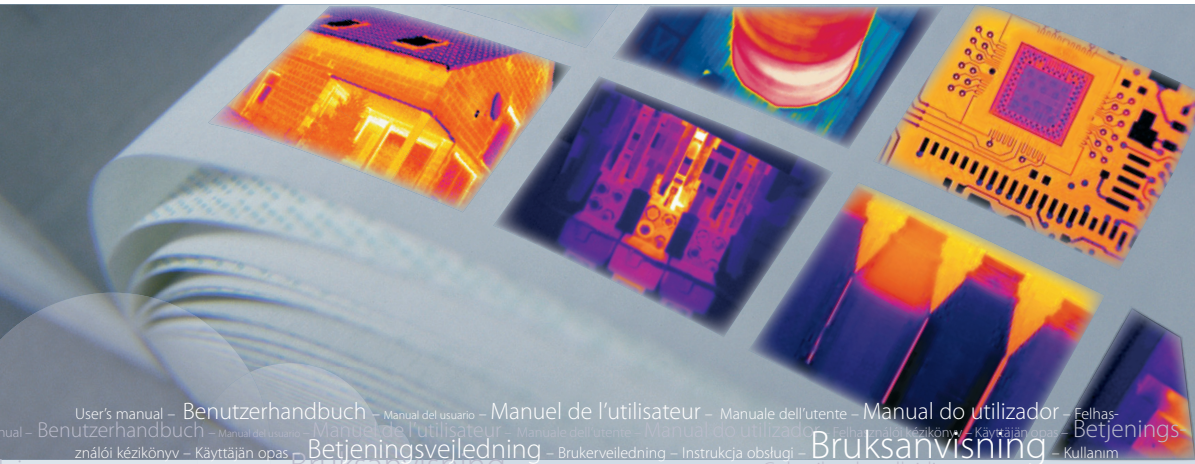
User's manual


User's manual – Benutzerhandbuch – Manual del usuario – Manuel de l'utilisateur – Manuale dell'utente – Manual do utilizador – Felhas-
ználói kézikönyv – Käyttäjän opas – Betjeningsvejledning – Brukerveiledning – Instrukcja obsługi – Bruksanvisning – Kullanım
Kılavuzu – Uživatelská příručka – Gebruikershandleiding

ThermaCAM™ Researcher

Basic edition. Version 2.8 SR-1

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ThermaCAM™ Researcher

User's manual

License number:

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1 Notice to user

Typographical conventions

This manual uses the following typographical conventions:

- **Semibold** is used for menu names, menu commands and labels and buttons in dialog boxes.
- *Italic* is used for important information.
- `Monospace` is used for code samples.
- UPPERCASE is used for names on keys and buttons.

Comments & questions

Make a report of errors you find, as well as your suggestions for new revisions. Send an e-mail to:

documentation@flir.se

Technical support

When you need technical support, make sure that you have the following information on hand:

- The camera model name
- The camera serial number
- The communication protocol, or method, between the camera and your PC (for example, Ethernet, USB, or FireWire)
- Operating system on your PC
- Microsoft® Office version
- Full name, publication number and revision number of the manual

You find the addresses and telephone numbers to local sales offices on the back cover of this manual.

Software updates

FLIR Systems regularly issues software upgrades and service releases on the support pages of the company website:

http://www.flirthermography.com

To find the latest upgrades and service releases, make sure you select **USA** in the **Select country** box in the top right corner of the page.

Training

To read about infrared training, visit this site:

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2 Welcome!

Thank you for choosing ThermaCAM™ Researcher!

This is the operator's manual of ThermaCAM™ Researcher. We are convinced that this program will be a useful tool when you explore the fascinating world of infrared imaging and measurements.

If you need the manual, but cannot find it, you can rely on that the same information is available as the help text of the program.

2.1 New features in ThermaCAM™ Researcher 2.8

ThermaCAM™ Researcher 2.8 has a number of changes mainly regarding the following:

- Indigo Merlin/Omega image formats (.img and .tgw)
- Standard Archive Format (SAF) output from Copy Selection and Image Save As.

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3 Installation

3.1 Installation instructions

We recommend that you first close all applications running on your computer (except for antivirus and firewall software).

If you have Windows NT 4.0, 2000 or XP, please log in as the Administrator during the installations.

3.1.1 Installation of the application software

ThermaCAM™ Researcher is installed by an installation utility program. It will guide you through the installation steps, and do most of the work. Just insert the CD-ROM and choose to start the installation of ThermaCAM™ Researcher from the installation window that appears.

During the installation, you will be asked to type in the license number. Your license number is unique, and can be found on the first page of the manual.

The directory structure of ThermaCAM™ Researcher is pre-set. The only adaptation you can make during the installation is to change the name of the directory in which the program is installed.

When the installation finishes, you may have to restart your computer.

After this installation, you will be able to start ThermaCAM™ Researcher from the Programs entry of the Start button menu.

3.2 Where do the installed files go?

On all Windows systems, the installation program builds a new directory tree, normally at C:\Program Files\ThermaCAM™ Researcher\, containing the following files:

ThermaCAM™ Researcher\	Executable files, help file
…\Images	Sample image files
…\Palettes	Palette files (scale color definitions)

The installation also adds some executable files into the main Windows directories.

On Windows 2000 and Windows XP, which are multi user systems, only administrator users may create and update files in the common **Program Files** directory. Ordinary users are not permitted to do that. Ordinary users have a place of their own where they can keep the data files of their programs. It is called **My Documents**.

On Windows 2000 and Windows XP, the \Images and \Palettes files are copied to a ThermaCAM™ Researcher subdirectory of the **My Documents** directory of each user when he, or she, starts to use the software. Then each user easily can modify them separately.

NOTE: These **My Document** files are not removed when you remove the program.

4 About the program

4.1 Basic principles for ThermaCAM™ Researcher

The main purpose of this program is to view, measure, and analyse IR images, sequences, and thermal events residing on the computer hard disk drive, or an external drive, server, CD-ROM, PC-Card etc.

The measurements are made with the following analysis tools: isotherm, spotmeter, area and line. The results produced by these tools can be displayed within the IR image, in the profile window, in the histogram window, or in the result table window. Formulas can be applied to the results.

The program uses a set of predefined screen layouts, one for each type of work that you could have in mind.

The clipboard functions **Copy** and **Paste** are used for this purpose.

Several copies of ThermaCAM™ Researcher can run at the same time.

4.2 List of current image files

The images that you handle with ThermaCAM™ Researcher are either stored one by one, where each image has a characteristic file name, or stored as a sequence thus indicating that they have something in common.

Such a sequence of IR images is stored in an image directory either as separate files or in a single file.

A list, a group of names of image files in the same directory, is what keeps the sequence together. You may change the list at will, adding or removing file names.

You can actually group any images you like into a fake sequence. The only restriction is that they have to be stored in the same directory on the disk. You do not have to include all the images of the directory.

Single file image recordings are normally quite large. ThermaCAM™ Researcher has functions that will let you edit these files. Then you are supposed to first open all images and then mark the images to be removed or copied as a selection.

4.3 Image directory

All the images of the same recording have to be placed in the same directory on disk. We call it *the image directory*. The full path name of the image directory is displayed in the program title bar.

4.4 Session files

You often need to be able to recreate particular situations (such as an experiment) during your work. ThermaCAM™ Researcher uses session files for this purpose. It stores for example the list of the currently open images in its session files. They do however not contain the images themselves.

The full path name of the image directory is also stored in the session file.

If you move the images (or try to reach them from another computer in which the image directory has another path), you will have to correct this path in order to be able to see the images again.

You may select a session file to become the default session. This means that every time you start ThermaCAM™ Researcher or order a brand new session, the default session settings and images will be fetched. The **Set Default Session** command is in the **File** menu.

Should you wish to avoid reading the default session, press SHIFT while ThermaCAM™ Researcher starts.

You deselect the default session by opening the default settings dialog box and clicking the **Cancel** button.

4.5 Program screen layout

10426503;a2

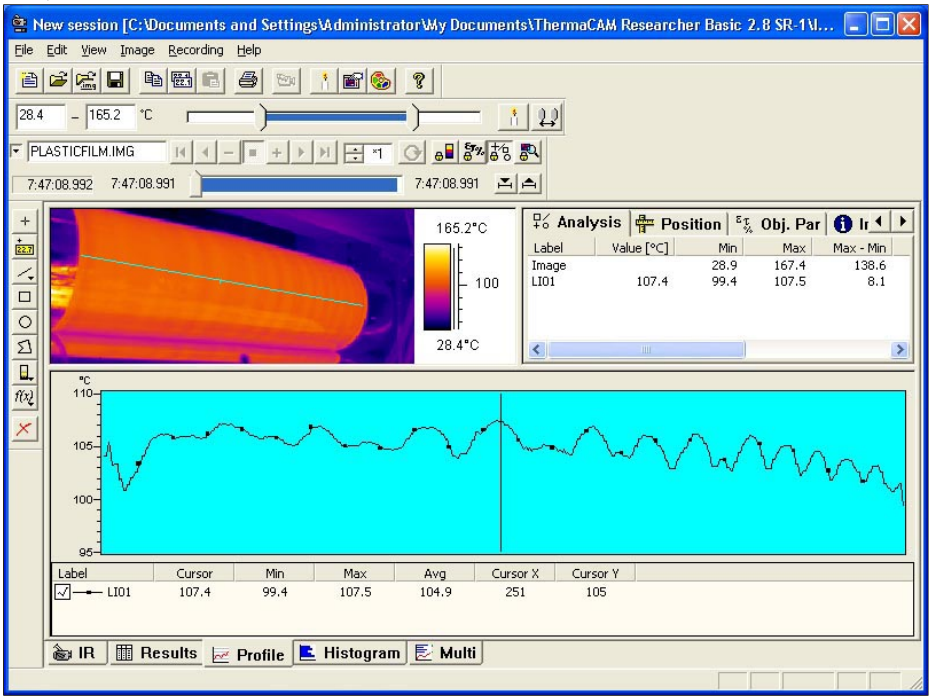

Figure 4.1 Main window

There are several layout options available. These are controlled by tabs in the bottom part of the ThermaCAM™ Researcher window. You can see combinations of the IR image, the profile, the histogram, and the result table windows. All tabs have an IR image with a temperature scale in the top left corner.

You cannot reposition the windows within the tabs, but you can catch and move the splitter bars that separate the windows, thus increasing or decreasing the relative size of each of the windows.

You can copy the whole program window to the clipboard by pressing the ALT + PRINTSCRN key buttons. You can also save the current tab as a bitmap by the command **Save Tab As** in the **File** menu

The program can only show one image at a time. On the image, the analysis tools are displayed. The results of the analysis tools can be displayed in the histogram, profile, result table window.

The main layout of the program is pretty much like any other Windows program. On the top line of the program window, there is a title containing a session name, the image directory and the three buttons, minimise, maximise and close, from left to right. The same functions are available on the right mouse button menu of the top line.

Below the top line, there is a set of drop-down menus by which you can select functions related to session/image filing (**File**), the clipboard (**Edit**), the screen layout (**View**), the display and analysis of the image (**Image**) and the playback of images (**Recording**).

There is also a large number of toolbar buttons. There are toolbar buttons for almost every function of the program. Every toolbar button has a short yellow description that will pop up if you hold the mouse cursor still for a while on top of it.

The toolbars are normally docked to the borders of the program window, but can be undocked and placed anywhere on the screen. Just double-click on them.

At the bottom of the program window, on the status line, a more detailed description of the menu items and tool bar buttons will be shown while you sweep through menus and over the toolbar buttons by the mouse cursor. Towards the right of this status line, there are keyboard indicators for Caps Lock and Num Lock.

4.5.1 Standard toolbar

10417703;a2

Figure 4.2 Standard toolbar

From left to right:

- Create a new session
- Open an existing session
- Open/add images to the current session
- Save the current session using the current name

10417803;a2

Figure 4.3 Standard toolbar, continued

From left to right:

- Copy the session file and the current image to the clipboard
- Copy values, such as analysis results, as text to the clipboard
- Paste a copied session into ThermaCAM™ Researcher. The name of the session is not pasted.
- Print the current image

10426703;a1

Figure 4.4 Standard toolbar, continued

From left to right:

- Switch on the function automatic adjustment of the image scale
- Bring up the image settings dialog box
- Bring up the palette selection dialog box

10418003;a2

Figure 4.5 Standard toolbar, continued

- Bring help from the manual

4.5.2 Play images toolbar

10418103;a2

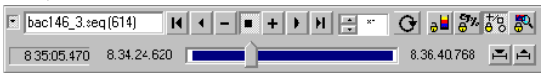

Figure 4.6 Play images toolbar

Top row:

- Show second row: ON/OFF
- Name of the current image. You may type a name or number in this field.
- 7 VCR style playback buttons. Stop in the middle.
- A control by which the replay rate is controlled
  - ***1** means full speed from disk
  - ***2** means twice full disk speed (i.e. every other image is not shown)
  - **÷2** means half full speed
- Auto rewind button
- **Lock temperature scale** button
- **Lock object parameters** button
- **Lock analysis tools** button
- **Lock zoom factor** button

The **Lock** buttons will, when pressed, let you keep the same temperature scale / object parameters / analysis tools / zoom factor for all images being replayed, regardless of what is stored inside the images. When you depress these buttons, the information of the images will be used instead.

Second row:

- Current image time/frame/trig count

- First image time/frame/trig count
- Slider. Move fast within your image sequence. The first image is to the left.
- Last image time/frame/trig count. The time/frame/trig count field depends on the **Presentation** selection in **Replay Settings** in the **Recording** menu. It is either absolute image time, relative time to first frame, frame number or trig count.
- Set selection start
- Set selection end

Start is always to the left of **End**. The slider will highlight the selected area within the sequence with a blue color.

4.5.3 Image dir toolbar

Figure 4.7 Image dir toolbar

- The image directory. You may edit this field to change it.
- Browse existing directories

4.5.4 Analysis toolbar

The following analysis tools exist (left to right):

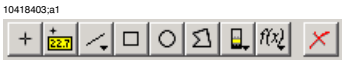

Figure 4.8 Analysis toolbar

From left to right:

- Spot meter
- Flying spot meter. Uses the mouse cursor.
- Line, with cursor
- Box area
- Circle area
- Polygon area
- Isotherm (above, below, interval)
- Formulas
- Removal tool

4.5.5 Scaling toolbar

Figure 4.9 Scaling toolbar

From left to right:

- Scale max temperature field. Editable.
- Scale min temperature field. Editable.
- Current measurement unit indicator
- Slider for the scale max and min temperature. Drag with mouse. **Min** is to the left.
- Automatic adjustment of the scale to the image: ON/OFF
- Lock span: ON/OFF. Changes apply only to the level.

The highlighted region in the sliders indicates the span of temperatures in the image. By selecting **Auto Adjust**, you will place the slider markers close to the ends of the highlighted area, but still inside it. A small part of the span is thus wasted.

4.6 Shortcut keys

Menu selections can be made from the keyboard. Press Alt + the key indicated on the menu line by an underscore. This brings up the menu. Then press the key indicated in the menu by an underscore to select that item.

In addition to the tool bars, there are a number of shortcut keys on the keyboard by which important functions can be reached:

Key combination	Explanation
ALT + F4	Exit
CTRL + A	Auto adjust image
CTRL + C	Copy session and image
CTRL + D	Play recorded sequence
CTRL + F	Freeze/Unfreeze image
CTRL + F2	Step backwards
CTRL + F4	Step forwards
CTRL + I	Open disk images
CTRL + N	New session
CTRL + O	Open session
CTRL + P	Print
CTRL + PAGE UP/DOWN	Changes max scale temperature
CTRL + R	Autorewind mode on/off
CTRL + S	Save session
CTRL + SHIFT + F2	Set selection start (within sequence)
CTRL + SHIFT + F4	Set selection end (within sequence)

Key combination	Explanation
CTRL + SHIFT + TAB	Previous main tab
CTRL + TAB	Next main tab
CTRL + V	Paste session
END	Last disk image
F2	Play backwards
F3	Stop playing
F4	Play forwards
HOME	First disk image
PAGE UP/DOWN	Changes min scale temperature
SHIFT + F2	Fast backwards
SHIFT + F3	Stop
SHIFT + F4	Fast forwards

5 Tutorials

5.1 How to play back images

ThermaCAM™ Researcher supports the following image formats:

- Thermovision 400/800 + 900/1000
- AGEMA 550/570 + ThermoVision Alert + ThermoVision Sentry
- Prism DS
- Inframetrics 700
- ThermaCAM PM 100, 200, 300, 150, 250, 350, 180, 280, 380
- ThermaCAM PM 525, 545, 575, 595
- ThermaCAM SC 1000, 2000
- ThermaCAM PM 195, 295, 395 (UltraCAM)
- ThermaSNAP
- ThermaCAM SC 3000
- Indigo Merlin (*.img and *.tgw)
- Indigo Omega (*.img and *.tgw)
- Indigo Phoenix (*.img)
- Thermoteknix *.tgw, *.tmw, *.tlw
- THV 400/800 Tdiff-images
- THV 900/1000 Tdiff-images
- Researcher Tdiff-images
- Single Ttx-tgw bilder from Dynamite
- Difference images i Temperature
- Difference images i Object signal
- FFF and FFF-jpg-images
- FPF-format (save only)
- FFF and JPG with Dual ISO and Diff
- Ttx-tgw images with AVG
- SEQ-files with text comments

5.1.1 Open images dialog box

You start the dialog box with this toolbar button (or by pressing CTRL + I keys or by the **File** and **Image** menus).

10421203;a2

Figure 5.1 Open images toolbar button

It will bring up the following dialog box:

10427003;a1

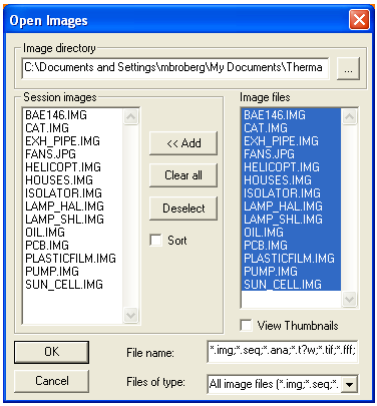

Figure 5.2 **Open images** dialog box

The top field of this dialog box permits you to edit the name of the directory where the images are stored. Click **OK** or the ENTER key once after editing this text in order to refresh the dialog box. The dotted button leads to a directory browser.

The left half of the dialog box shows the list of images currently in use by this session.

The right half of the dialog box shows a list of image file names in the image directory. All the files in this list are highlighted by default.

There is a file name filter field by which you can affect the directory listing. You could for instance change *.img to t*.img to list files beginning with the letter t. Click **OK** or the ENTER key once to refresh the list afterwards.

If you select the **View Thumbnails** option, the layout of the right half of the dialog box will change drastically:

10427103;a2

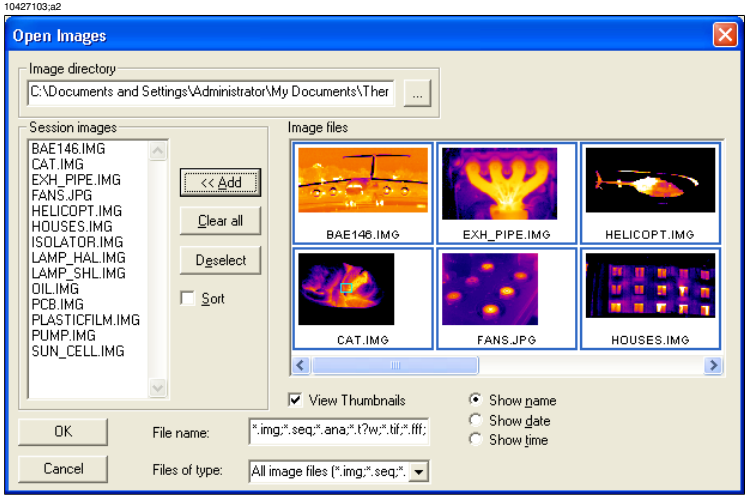

Figure 5.3 **Open images** dialog box – **View thumbnails** option selected

The list of files will become a list of images instead. The images with a blue frame are the highlighted ones. The images are always displayed with the iron palette and with their own scale, object parameter, analysis and zoom settings.

Using the three radio buttons below the images, you have the option of displaying the date or time instead of the image names.

The buttons in the middle of the dialog box manipulate the names of the list to the left. The **<< Add** button will copy all highlighted file names from the right list to the left one. The **Clear All** button will clear the left list. The **Deselect** button will remove highlighted items in the left list. If no items are highlighted, nothing is removed. The image files are not deleted from disk by this operation, only their names in the list.

The **Sort** selection will rearrange the names in the left list. They become sorted in alphabetical order and duplicate names are removed.

This gives you the possibility to arrange the list of names, as you like.

You should use mouse clicks in combination with holding down the SHIFT or CTRL keys in order to manipulate the highlighting of the lists.

You may add both single images and image sequence files to the left list at the same time, although it is probably not very common practice.

When clicking **OK**, you select all the image files in the list to the left for playback by ThermaCAM™ Researcher.

5.1.2 Play images toolbar

When disk images are being replayed, this toolbar is displayed:

10421503;a2

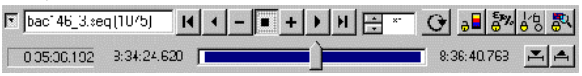

Figure 5.4 **Play images** toolbar

It resembles the controls found on ordinary video tape recorders quite a lot. You can step forward and backward one image at a time. You can play your images in any direction fast or slowly or jump to the end/beginning of the images.

You set the replay rate in the list box.

- ***1** means full speed from disk
- ***2** means twice full disk speed (i.e. every other image is not shown)
- **÷2** means half full speed

You can double-click on the control to make it return to ***1** speed.

10421603;a2

Figure 5.5 Selection buttons for parts of images

These two buttons let you select one part of the current images. Click the left one when you are looking at the first (leftmost) image to be selected. Click the right one when you look at the last (rightmost) image to be selected. A blue indicator will mark your selection in the control.

When you have marked a selection, the "to end/to beginning" buttons will instead jump to the next mark and the autorewind button will change its behaviour. Printouts can be made based to the selection and, in the case of a sequence file being displayed, editing of this file can take place.

You can remove the selection by choosing **Clear Markers** in the **Recording** menu

10421703;a2

Figure 5.6 **Autorewind** toolbar button

This button enables autorewind mode. If a selection is made, it will be repeated continuously when replayed. If no selection is made, or autorewind mode is set to **All images**, the whole sequence is repeated.

The text field to the left shows the name of the current image in the sequence. This field can be edited if you click in it. You may write:

- A file name, including the extension, present in the list
- The number of a particular image. 1 signifies the first image
- A relative number. +5 means five images ahead. -12 means twelve images back

Hit ENTER on the keyboard to finish the editing.

SEE ALSO: For information about associated shortcut keys, see section:

- 4.6 – Shortcut keys on page 13

10421803;a2

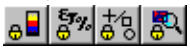

Figure 5.7 Control buttons used when switching images

These four buttons control how the program behaves when you switch from one image to another.

SEE ALSO: For more information about these buttons, see section:

- 5.5.1 – Making measurements in playback on page 41

5.1.3 Replay Settings dialog box

If you choose **Replay Settings** from the **Recording** menu the following dialog box will appear.

10421903;a1

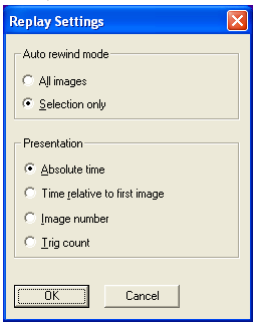

Figure 5.8 **Replay settings** dialog box

Auto rewind mode: In rewind mode you can chose between repeating the whole sequence or just the marked part.

Presentation: What is presented on the play images toolbar.

Absolute time shows the actual recording time.

Time relative to first image shows the time difference of the current image compared to the first image. If the current image is recorded earlier than the first image, ######## is shown instead.

Image number shows the image ordinal number.

Trig count shows the external trig count stored in the image.

5.2 How to edit/convert sequences

It will happen now and then that you would like to extract the essential part of a sequence and/or convert it to some other image format, such as AVI or BMP.

To edit a sequence of images, open it with the **Open Images** dialog box and use the **Selection Start**/**Selection End** buttons on the **Play Images** toolbar to mark some images. Step to the first image you intend to edit and click the left one of the buttons, then step to the last image to edit and click the right one. A blue ribbon will be shown in the image slider control.

10422003;a1

Figure 5.9 Selection buttons for parts of images

5.2.1 Removing/Copying all selected images

Having selected some images, you can choose **Remove Selection** from the **Recording** menu. Then you will be asked to confirm it is the right selection.

You cannot undelete images that become removed. Depending on the sequence size this operation may take several minutes. The frame numbers of the images following the removed part will be resequenced.

Removing images only works if all the images are in the same sequence file (.seq)

Instead, if you choose **Copy Selection** from the **Recording** menu, and then choose output format **Seq**, you may select a directory and enter a file name for the new sequence file. Depending on the size of the selection this operation may also take several minutes.

Copying images in this way only works if all the images are in the same sequence file (.seq)

5.2.2 Removing/Copying some selected images

Having selected some images, you can also choose **Reduce Selection** from the **Recording** menu. This dialog box will appear:

10422103;a1

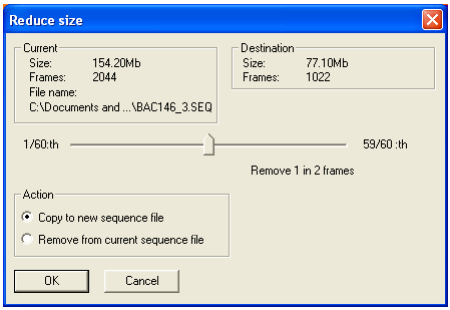

Figure 5.10 Reduce size dialog box

If you move the slider in the centre of the dialog box to the right, more of the sequence file is kept. If you move it to the left, less is kept.

Select whether or not you wish to copy the sequence to a new file, and click OK.

You cannot undelete images that become removed. Depending on the sequence size this operation may take several minutes. The frame numbers of the images following the removed part will be resequenced.

The reduction works only if all the images are in the same sequence file (.seq)

5.2.3 AVI/BMP/MatLab/FPF/SAF files from selected images

Having selected some images, you can convert them to other image formats by choosing **Copy Selection** from the **Recording** menu. This dialog box will appear:

10427203;a1

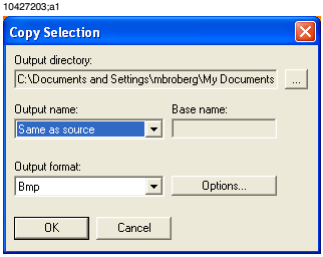

Figure 5.11 Copy selection dialog box

Set the output directory, output name and options of preferred output format and click OK to start the copy. Depending on the size of the selection this operation may also take several minutes.

SEE ALSO: For more information about output formats, see section:

- 5.4.15 – Studying whole images on page 37

SAF (Standard Archive Format) files can only be created if all the selected images belong to the same sequence. The created images will get the following file name extensions:

- *.stmov, *.inc, and *.pod, respectively, if a sequence or part of a sequence is saved
- *.sfimg if one image in a sequence is saved

If you click the options button when the output format is AVI, you will be able to set the AVI codec to **other**. This, in turn, causes the **Copy Selection** dialog box to show the following dialog box when you click its **OK** button.

10427303;a1

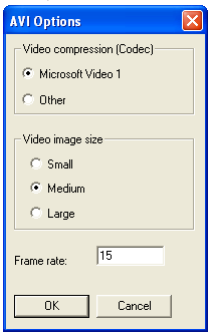

Figure 5.12 AVI options dialog box

Here you can choose among the compressors installed in your computer and configure them. Note that some of them might only be able to decompress AVI files, not to compress the files.

You should always check that the receiver of the AVI file is able to decompress it.

NOTE: AVI creation using 256 colors may cause problems. If you experience difficulties, please use a higher number of colors.

5.3 How to display an IR image

5.3.1 Obtaining a good IR image

You should now consider the object parameters (emissivity, reflected temperature, atmospheric temperature, relative humidity of the air, the distance and the external optics transmission and temperature). They describe the physical properties of the body of interest and its environment and the atmosphere between the object and the camera. You can reach them via **Settings** in the **Image** menu or this button:

10419903;a1

Figure 5.13 Image settings toolbar button

SEE ALSO: For more information about object parameters, see sections:

- 7 – Thermographic measurement techniques on page 51
- 10 – Theory of thermography on page 67
- 11 – The measurement formula on page 77

10426803;a2

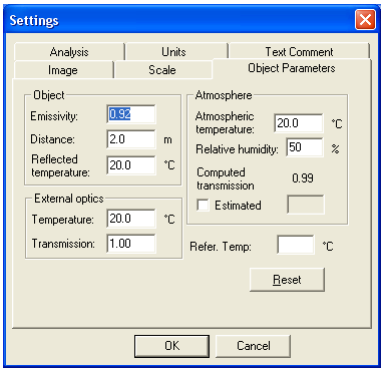

Figure 5.14 Settings dialog box

It is important that these parameter values become correct. Otherwise the scale temperatures and displayed colors will be wrong. The image parts for which the object parameters are wrong will get incorrect temperatures and colors. The measurement functions have object parameters of their own which are used to handle the case when there are two different targets in the same image.

SEE ALSO: To calculate the emissivity of an object, see section:

- 5.4.9 – Emissivity calculation on page 33

If the colors of the image are inappropriate, you can change them. The selection **Palette** toolbar button will bring up a dialog box with the palettes available.

10420103;a1

Figure 5.15 Palette toolbar button

Contrary to what you might think, the **Show saturation colors** option enables specific coloring of image points, which are outside the current temperature scale. The **Show out of range colors** option enables specific coloring of image points, which are outside the detectable range of the camera.

You can change the temperature scale with this control bar:

10420203;a2

Figure 5.16 Control bar

You can use the slider to search for a good scale or to set fixed limits. Remember that the maximum temperature always has to exceed the minimum temperature. Click on the input fields if you want to edit them and hit the ENTER key afterwards. If you select **Auto Adjust**, you will find that an attempt to find the optimum scale is made for each new image. A small part of the temperature span of the image is however wasted, to minimise the effect of noise in the image. The measurement areas have a related auto adjustment function, which adjust the scale based on the area.

5

The rightmost button will keep the distance between the slider controls fixed.

Sometimes, when a live camera image is shown, you can find it impossible to change the scale in ThermaCAM™ Researcher. This is when the camera has been set to continuously adjust the level or span of the image. Switch that camera setting off.

Finally, in the **Image** tab of the **Settings** dialog box, there are a few more options you can explore:

10426903;a1

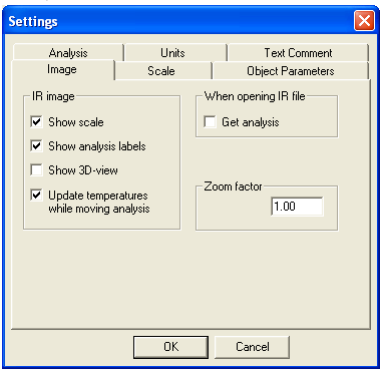

Figure 5.17 **Image** tab of the **Settings** dialog box

The **Show scale** option switches the display of the temperature and color scale on/off.

The **Show analysis labels** option will switch the display of the label texts on/off.

The **Show 3D-view** option will display a pseudo-3D version of the image.

The **Update temperatures** option has to do with the update of the profile, histogram and result table when analysis tools are moved around in the image.

The **Get analysis** option should not be used unless your images contain analysis tools that vary from image to image, which normally isn't the case.

The **Zoom factor** makes it possible to temporarily enlarge the centre of an image.

5.3.2 Transferring an IR image with OLE

If you want to display your image in a program not designed for IR images, you have to use OLE to make it visible. Use the **Copy session and image** toolbar button or the same command of the **Edit** menu.

10420503;a1

Figure 5.18 **Copy session and image** toolbar button

5.4 How to make single image measurements

Sometimes you just need to look at an IR image to measure it. You can look for anomalies, hot or cold areas and get an impression of their temperatures just by comparing the colors with those of the temperature scale. By choosing a suitable scale and palette, such things can be made to appear quite clearly. This chapter will, however, be devoted to something else: how to use the analysis tools to get numerical temperatures and statistical information out of a single image.

The analysis tools will show their results in the result table, profile or histogram window or directly inside the IR image. Results are also available through the OLE functions, such as **Copy Value**.

Both absolute measurements (i.e. the result is a real temperature) and relative measurements (i.e. the result is a difference temperature) can be made. The relative measurements are made relative to the reference temperature that you can enter in the dialog box **Image Settings** (in the **Image** menu), the **Object Parameters** tab.

The analysis tools are applied by activation of one toolbar button at a time. These are in this toolbar:

10422803;a2

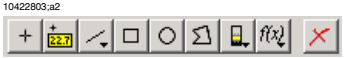

Figure 5.19 **Analysis** toolbar buttons

When you click on one of these buttons (except the formula button), it will stay depressed until you have dragged the analysis tool inside the IR image or the color scale. If you change your mind, click on the button again, and it will pop up.

If you hold the CRTL button of the keyboard down while placing the tool on the image, the button will stay down and you will be able to continue adding another tool of the same kind. The removal button works in the same way.

Once the symbols have been drawn, you get the opportunity to bring up a menu for each symbol by "hovering" with the mouse cursor above the symbol and clicking with the right mouse button. The symbol will respond by changing its color (and the mouse cursor) when you can catch it.

Formula results are not presented in the IR Image, instead they are available in the result table, and through OLE functions.

Three of the toolbar buttons are equipped with menus that you can activate by moving the mouse a little before releasing the mouse button. This is indicated with a small arrow facing downward on those buttons.

5.4.1 Isotherm tool

An isotherm is a marker in an infrared image that highlights areas where the radiation from the object is equal. The name isotherm can be misleading, since it implies that equal temperatures are highlighted. This is only true if the emissivity of the object is the same all over the image.

If you bring up the menu on this button, you will see that there are five types of isotherms in ThermaCAM™ Researcher. The most commonly used one is the **Interval** isotherm. It will highlight a temperature interval with a certain (selectable) width. There is a marker in the color scale to indicate the position of the isotherm. The temperature measurement value associated with the interval isotherm is taken at the top of the isotherm, regardless of how wide it is.

The **Above** isotherm will highlight all temperatures above a temperature value and the below isotherm the opposite.

Dual above and **Dual below** isotherms are an above/below isotherm attached to an interval isotherm with a different color. The dual isotherms highlight two temperature spans.

You activate the tool and set its level by clicking on the color scale beside the image. If the scale has been switched off in the **Image Settings** dialog box, you have to switch it on again.

Isotherms can be viewed in a transparent mode. Select the **Analysis** tab from the **IR objects settings** dialog box and select the transparent isotherm check box.

Transparent isotherm is best viewed with a grey palette, because the isotherm will always be presented in the image with red for above, green for interval and blue for below. If two isotherms of the same kind are present, the latest added isotherm will be shown in yellow.

It is possible to change the isotherm level after it has been created. You “catch” the level in the color scale by pressing the left mouse button precisely on the level and pull it to where you want it to be. Then release the left mouse button. The interval isotherm can be changed in three ways. You can catch it in the upper and lower ends, changing them. You can also catch it in the middle and move both ends at the same time.

Isotherm limits cannot exist outside the maximum or minimum temperatures of the scale. Hence they will follow the scale limits, if the span of the scale is reduced.

You can use two isotherms with different colors at the same time.

The temperature values of the isotherm are shown in the result table window or through OLE. You can obtain the following values: Temperature, width (interval isotherm only) and temperature relative to the reference temperature.

The temperature value given for the interval isotherm, is that of the upper limit.

The isotherm always uses the object parameters of the IR image.

5.4.2 Spot meter tool

This tool measures the temperature in one spot on the image and shows the result in the result table or beside its symbol in the IR image. You can obtain the following values: Temperature, temperature relative to the reference temperature, emissivity, object distance and the image co-ordinates of the spot meter.

Spot meters are called **SP01**, **SP02**... **SP99**.

You create a spot meter by first clicking on the spot meter toolbar button and then on the desired position in the image.

You move a spot meter by “catching” it with the mouse. You click the left mouse button on top of the cross hair and drag it into the place you want. The spot meter will then jump to that position.

5.4.3 Flying spot meter

This tool only measures the temperature at the mouse cursor and displays it beside the cursor in a tool tip window.

There is just one single flying spotmeter.

You can click with the left mouse button on the image to create fix spotmeters in that position, if you like.

5.4.4 Area tool

This tool measures the maximum, minimum, average and standard deviation temperature within a chosen part of the image and presents these values in the result table window or beside its symbol in the image. Results can also be displayed graphically in the histogram window. The results are also available through OLE.

You can obtain the following values: Minimum, maximum, average and standard deviation temperature, the same relative to the reference temperature (except for the deviation), emissivity, object distance and the image co-ordinates of the area.

Areas are called **AR01**, **AR02**... **AR99**.

You create a box area by first clicking down the box button and then moving the mouse to one of the corners of the new box. Hold the left mouse button down and drag the mouse to the opposite corner and release the button.

You create a circle area by first clicking on the circle button and then moving mouse to the centre of the new circle. Hold the left mouse button down and drag the mouse to some place on the circle border and release the button.

You create a polygon area by first clicking on the polygon button and then moving mouse to the first corner of the new polygon area. Click the left mouse button for each new corner and double click or hit the ESC key to finish adding corners.

You move an area by “catching” it with the mouse. You hold the left mouse button down inside the area and drag the whole area into the new position and release the button. If you hold down the CTRL key while moving the area, you create a copy of the area instead of moving it.

You reshape an area by catching the border or corner to be changed and dragging it along. Catching and dragging a polygon area border results in adding a new corner. You can remove a specific corner from a polygon area by using the analysis removal tool.

Areas can also be used to make local auto adjustments. That means adjusting the scale of the whole image to the temperature span within that particular area. It is very useful, if you want to make detailed studies of some part of the image. This function is only available on the right mouse button menu of the areas.

5.4.5 Line tool

This tool measures the minimum, maximum, average and standard deviation temperature along a straight or bendable line within the image. The temperature in one spot, the line cursor, can also be measured. These values are presented in the result table or beside the line symbol in the image. The line temperatures can also be graphically presented in the profile window. You can obtain the following values: Cursor, minimum,

maximum, average and standard deviation temperature, the same relative to the reference temperature (except for the deviation), emissivity, object distance and the image co-ordinates of the line and a string with all the temperatures of the line.

Lines are called **LI01**, **LI02**... **LI99**.

You create a straight line by first clicking on the line button and then move the mouse to one of the ends of the new line. Hold the left mouse button down and drag the mouse to the other end and release it.

You create a bendable line by first clicking on the line button, and then drag the mouse just a little. A menu will now appear. Select the **Bendable line** item and start clicking on the image wherever you want the corners to be placed. Double-click with the mouse or press the ESC key to finish the creation.

You create a line cursor by first pressing the left mouse button on the line toolbar button while dragging the mouse to bring up the menu. Select the cursor item and move the mouse to the place on the line where you want to have the marker and click. You can see the temperature of the marker now in the profile window.

You move a line by “catching” the corners with the mouse. You hold the left mouse button down on the corner and drag it away. You can move the whole line by catching it in the middle.

You move its cursor by “catching” it and dragging it along the line. If you hold down the CTRL key while moving the line, you create a copy of the line instead of moving it.

5.4.6 Formula tool

This tool is used for adding and editing formulas.

A formula can contain all common mathematical operators and functions, such as +, -, *, / square root, etc. Also, numeric constants such as 3.14 can be used. Most importantly, references to measurement results, formulas and other numerical data can be inserted into formulas.

The formula button has a menu. If you bring up the menu you will find some frequently used formulas to add, in addition to entries leading to an add formula dialog box and an edit formulas dialog box.

The result of the formulas appears in the result table.

Click the **Formulas** toolbar button. The **Edit formulas** dialog box will appear:

10427403;a1

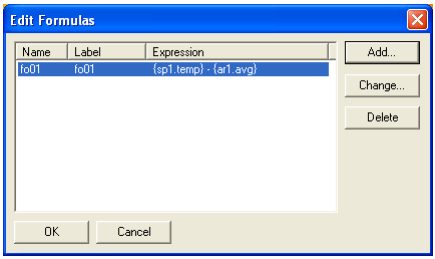

Figure 5.20 **Edit formulas** dialog box

Click **Add**, and another dialog box will be displayed, in which you define your new formula.

10427503;a1

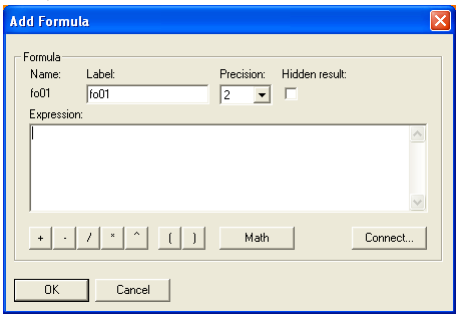

Figure 5.21 **Add formula** dialog box

The formula name is generated automatically and identifies the formula uniquely.

In the **Label** field, type a text describing your formula. This label will appear in the result table window.

Now, enter the expression of the formula. You may either type in the expression using the keyboard, or use the buttons in the dialog box. When you click on any of the buttons, the corresponding operator will be inserted into the expression. Following are the operators that can be used.

Operator button	Operator
+	Plus operator
-	Minus operator
/	Division operator
*	Multiplication operator

Operator button	Operator
^	Power operator
[ ]	Parentheses, used for grouping

If you want to use other mathematical operators, such as sinus, select the appropriate function by clicking the **Math** button. Following are the functions that can be used.

Function name	Function
Acos	Arccosine
Asin	Arcsine
Atan	Arctangent
cos	Cosinus
log	Natural logarithm
log10	Base-10 Llogarithm
sin	Sinus
sqrt	Square root
tan	Tangent

Typically, your formula will contain references to other sources of data, such as measurement functions of IR images. To select a data source, click the **Connect** button. A dialog box will appear. Select the **Object** and **Value**, and click **OK**. This will insert a reference address into your expression. The address will be substituted with the actual value when the formula is used.

For the example above, with the spot and area items, you would do the following to add a formula that is defined as the subtraction of the spot temperature and the area's average temperature:

- Type a suitable label for the formula in the **Label** field, such as **Spot – Area**
- Click the **Connect** button. Select **Spot** from the **Object** list and **Temperature** from the **Value** list and click **OK**. This will insert the address **{sp1.value}** into your expression.
- Click the button labelled –. This will insert a minus sign into your expression.
- Again, click the **Connect** button. This time, select the **Area** from the **Object** list and **Average temperature** from the **Value** list and click **OK**.

Your expression should now read **{sp1.temp} – {ar1.avg}**.

You may also specify the precision of the formula, i.e. the number of decimals with which the result of the formula will be displayed. Do this by selecting the appropriate value from the **Precision** list. You can use 0–5 decimals.

To prevent the formula from presenting its result in the result table, select **Hidden result**.

Once finished, click the **OK** button. This brings you back to the **Formulas** dialog box. To add more formulas, repeat the procedure.

Another interesting formula you could try, is

({sp1.temp} ^ 4) * 5.57033e-8 / 3.141592 [W/m ^ 2/sr]

which calculates the blackbody radiance, when the temperature is in Kelvin. (**5.57033e-8** means 5.57033 x 10^{-8})

The command **Change** gives you the opportunity to change a defined formula. Selecting a formula is done by clicking on it. Double-clicking it will open the **Change Formula** dialog box directly. The **Delete** button removes the selected formula.

NOTE: Any text that follows the expression will be displayed, as is, in the field connected to the formula. For instance, your expression may be **{sp1.value} * {dobj} meters**.

5.4.7 Removal of analysis tools

You remove analysis tools by clicking the removal tool in the analysis tool box down, i.e. the red X. You then move the mouse to an analysis tool and click to remove it. All analysis tools including line cursors and isotherms can be removed in this way.

If you happen to click this button by mistake, click on it again to deactivate the function.

In the **Image** menu, there is a command that will remove all the active analysis tools (formulas excluded) at once. All the active formulas may be removed by a separate command in the **Image** menu.

5.4.8 Analysis tool styles and object parameters

You can affect the way in which analysis tools appear in the image. You can also change some of the object parameters used. Click this button to bring up the **Image Settings** dialog box or select **Settings** from the **Image** menu:.

10423803;a2

Figure 5.22 Image settings toolbar button

The **Analysis** tab looks like this:

10427603;a1

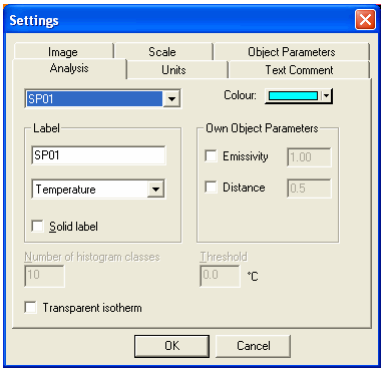

Figure 5.23 Analysis tab of the **Image settings** dialog box

First, use the list in the top left corner of the dialog box to select the appropriate analysis tool.

Then, write some short descriptive name in the text field below, unless you think that LI01 will do. This text will be shown beside the analysis symbol.

Further down the dialog box, there is a list box that allows you to display one measurement result beside the analysis symbol.

If you click in the **Solid label** box, the text beside the symbol will be displayed on a black background. This increases the visibility but hides more of the image.

You can also change the color of the analysis symbol, in case it happens not to be visible enough.

Frequently, the object emissivity or distance is varying between different parts of the IR image. All analysis tools (except the isotherm) can be forced to use their own values on these object parameters. Click in the box to the left of the parameter to enable the function and fill in the desired value to the right. The value shown before was the corresponding value of the object parameters of the image.

SEE ALSO: For more information about threshold, see section:

- 5.7.2 – Using a threshold on page 45

You may change more than one analysis function before clicking **OK**.

5.4.9 Emissivity calculation

The emissivity factor of an object can be calculated if you know its temperature and the temperature value is well above or below the ambient temperature.

Put for instance a box area on the object for which you know the temperature. Select **Emissivity Calculation** from the right mouse button menu of the area.

Enter the known temperature and click on **Calculate** to view the new emissivity. Click **OK** to accept and apply the new emissivity to the area.

10427703;a1

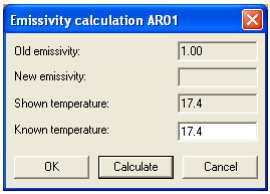

Figure 5.24 Emissivity calculation dialog box

5.4.10 Result table window

The result table presents measurement data from the IR image and from the analysis symbols. You can switch on/off the presentation of specific values from the settings dialog box reached by the right hand mouse button of the mouse.

5.4.10.1 Analysis tab

10424103;a1

Analysis | Position | Obj. Par | Image | Text comment

Label	Value [°C]	Min	Max	Max - Min	Avg	Stdev	Result	Expression
Image		32.0	105.6	73.6				
SP01	65.5							
SP02	102.6							
LI01		36.3	100.6	64.3	73.0	17.6		
AR01		60.5	101.5	41.0	83.7	10.1		

Figure 5.25 Analysis tab of the result table

Analysis symbols having their own object parameters have their labels marked with an asterisk.

If the difference temperature option is available and selected in the settings dialog box, then the reference temperature is displayed on the first line in the **Temp**. column. Results affected by the reference temperature are displayed on two lines, one line subtracted by the reference temperature and the other one as usual.

The expression and result columns present formulas and the result values.

5.4.10.2 Position tab

This tab shows the coordinates for spots, lines and areas. All coordinates are relative to the IR image top left corner. For a polygon area, the coordinates are those of a circumscribed rectangle.

10424203;a1

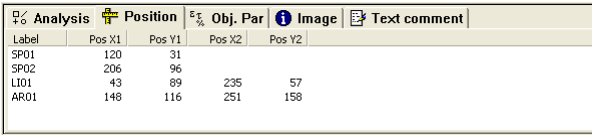

Figure 5.26 Position tab of the result table

5.4.10.3 Object parameter tab

The IR image object parameters are always displayed according to the settings dialog box. Analysis symbols having their own object parameters are also shown. Their labels are marked with an asterisk.

10424303;a2

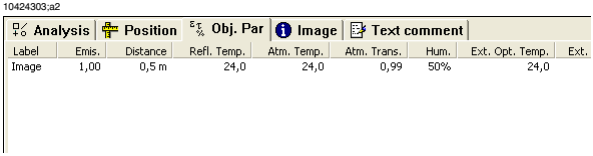
Analysis
Position
Obj. Par
Image
Text comment
Label Emis. Distance Refl. Temp. Atm. Temp. Atm. Trans. Hum. Ext. Opt. Temp. Ext.
Image 1,00 0,5 m 24,0 24,0 0,99 50% 24,0

Figure 5.27 Object parameter tab of the result table

5.4.10.4 Image tab

The image tab shows IR image data. From the settings dialog box, select a set of data to be shown.

10430103;a1

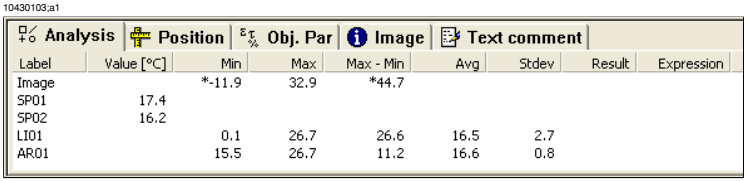

Figure 5.28 Image tab of the result table

5.4.11 Interpretation of *>< values

Sometimes, when you accidentally make measurements almost outside the calibrated range of a camera, or when you enter extreme object parameters, you will get ***s** in front of or replacing the desired values. You may also get > or < characters in front of the values. In all these cases you are out of range.

5.4.12 Transferring single results with OLE

If you want to see result values not shown on the IR image or to process the values in other programs, then you should use OLE. First you click this toolbar button, or select **Copy value** from the **Edit** menu:

10429903;a1

Figure 5.29 **Copy value** toolbar button

This will bring up the **Copy Value** dialog box:

10430003;a1

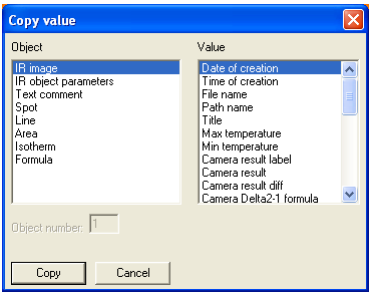

Figure 5.30 **Copy value** dialog box

Then, click in the left column on the appropriate type of object and fill in the ordinal number in the text box below. **SP01** corresponds to spot object 1. Click in the right column on the desired value.

Click **Copy** and this value can now be copied into other applications.

5.4.13 Transferring the result table with OLE

Click inside the result table window with the right hand mouse button and select **Copy**. In the receiving application, for example MS Excel, select **Edit Paste**. The whole result table is transferred.

5.4.14 Measurement output and units

You can select the temperature unit and distance unit you want the analysis tools to work with at the **Units** tab of the **Image Settings** dialog box that you bring up from the **Image** menu or with this button:

10424603;a2

Figure 5.31 **Image settings** toolbar button

The temperature unit is also used in the temperature scale.

10427803;a1

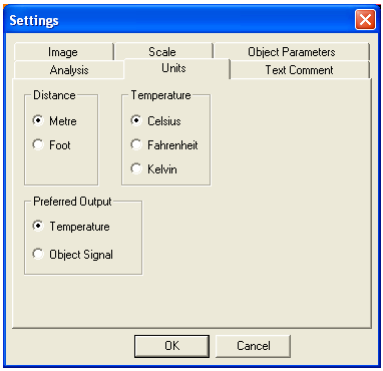

Figure 5.32 **Settings** dialog box

From the same dialog box, you can also set the preferred measurement output:

- The **Temperature** value is calibrated with a set of reference blackbodies.
- **Object signal** is a non-calibrated value approximately proportional to the amount of radiation sensed by the detector. It will change from camera to camera and between the measurement ranges.

5.4.15 Studying whole images

Users of MatLab or MS Excel will find it convenient to be able to study images themselves. The selection **Save As** in the **Image** menu leads to a dialog box in which the current image can be saved in various formats:

- **MatLab** format, with one double precision value for each element of the image
- **FLIR Public Format** file format, with one single precision value for each element of the image
- **BMP** (bitmap) format, with or without analysis. Can only be used to view the images.
- **CSV** (comma separated value) format. The temperatures of the whole image is stored in a text format that MS Excel can read. The character that separates the temperatures in the file is fetched from the Windows regional settings.
- **SAF** (Standard Archive Format) was created for flexible and extensible use in data archiving. Although the data may be in ASCII or one or several binary formats, the file header is plain ASCII text and therefore human readable.

SEE ALSO: For more information, see section:

- 5.4.16 – Studying whole images with MatLab on page 38
- 5.4.17 – FLIR Public image format on page 39

There is also the **Save Tab As** command in the **File** menu, which saves the current tab (i.e. both the image and the adjacent graphs) as a bitmap file.

5.4.16 Studying whole images with MatLab

ThermaCAM™ Researcher uses a simple MatLab matrix format. The binary file begins with five 4-byte integers structure. This is how it is described in C++:

```
typedef struct {  // MatLab file header (level 1.0)
   long type;     // 0 Intel type
   long mRows;    // Image height
   long nCols;    // Image width
   long imagF;    // 0 No imaginary part
   long namLen;   // Length of the matrix name + 1
} MatLabHeader;
```

This is followed by the name of the matrix, which corresponds to the name of the .mat file. This name must begin with a letter and not contain any strange character for MatLab to be able to read the file. In MatLab 7, this name can not have more than 7 characters.

The name is followed by nCols*mRows 8 byte double precision float numbers, each containing the current value of one point in the image, column by column.

```
XXXX(1,1):              Top left corner of the image
```

The image value matrix is followed by four extra one column matrices containing data about the stored image. Example for image XXXX:

```
XXXX_DateTime(1,1):     Year
XXXX_DateTime(1,2):     Month
XXXX_DateTime(1,3):     Day
XXXX_DateTime(1,4):     Hour
XXXX_DateTime(1,5):     Minute
XXXX_DateTime(1,6):     Second
XXXX_DateTime(1,7):     Millisecond
XXXX_ObjectParam(1,1):  Emissivity
XXXX_ObjectParam(1,2):  Object distance
XXXX_ObjectParam(1,3):  Reflected Temperature
XXXX_ObjectParam(1,4):  Atmospheric Temperature
XXXX_ObjectParam(1,5):  Relative Humidity
XXXX_ObjectParam(1,6):  Computed atm. transmission
XXXX_ObjectParam(1,7):  Estimated atm. Transmission
XXXX_ObjectParam(1,8):  Reference Temperature
XXXX_ObjectParam(1,9):  External optics temperature
XXXX_ObjectParam(1,10): External optics transmission
XXXX_Scaling(1,1):      Blackbody range min
XXXX_Scaling(1,2):      Blackbody range max
XXXX_Scaling(1,3):      Type of output
                         0 = temperature
                         2 = difference temperature
                         4 = object signal
                         5 = difference object signal
XXXX_Scaling(1,4):      Camera scale min
XXXX_Scaling(1,5):      Camera scale max
XXXX_Scaling(1,6):      Calculated scale min
XXXX_Scaling(1,7):      Calculated scale max
XXXX_Scaling(1,8):      Actual scale min
XXXX_Scaling(1,9):      Actual scale max
XXXX_FrameInfo(1,1):    Image number
XXXX_FrameInfo(1,2):    Trig count
```

5.4.17 FLIR Public image format

The "xxxx.fpf" files consist of a header followed by a matrix of single precision IEEE floating point values, each representing one point of the image.

A C-style description of the header layout can be found in the header file fpfimg.h, available in the Examples sub-directory of the installation.

The current version of the format is 2, in which:

- The xSize, ySize and ImageType fields are properly set.
- The spare fields are zeroized.
- The image point values are stored starting from the top left and row by row.

FPF images can only be saved by ThermaCAM™ Researcher, not read.

The basic data types are:

Char	8 bit	Often represents ASCII characters, may represent an 2's complement 8 bit integer (-128 - +127)
Unsigned char	8 bit	8 bit integer number (0 - 255)
Short	16 bit	16 bit integer (2's complement)
Unsigned short	16 bit	16 bit integer
Long	32 bit	32 bit integer (2's complement)
Unsigned long	32 bit	32 bit integer
Float	32 bit	IEEE floating point number, sign + 23 bit mantissa + 8 bit exponent, Representing numbers in the range +/- 10^{38}
Char[<len>]	Len * 8 bit	ASCII character string, most certainly terminated with the NUL character (=0)
Int	32 bit	32 bit integer (2's complement)

Multiple byte data types are stored with the least significant byte first.

5.4.17.1 The whole header data structure (size 892 bytes)

```
typedef struct
{
   FPF_IMAGE_DATA_T  imgData;
   FPF_CAMDATA_T     camData;
   FPF_OBJECT_PAR_T  objPar;
   FPF_DATETIME_T    datetime;
   FPF_SCALING_T     scaling;
   long  spareLong[32];    /* = 0 */
} FPFHEADER_T;
```

5.4.17.2 The image data structure (120 bytes)

```
typedef struct
{
   char fpfID[32];                 /*  "FLIR Public Image Format" */
   unsigned long  version;         /*  = 2 */
   unsigned long  pixelOffset;     /*  Offset to pixel values from
                                       start of fpfID. */
   unsigned short ImageType;       /*  Temperature        = 0,
                                       Diff Temp          = 2,
                                       Object Signal      = 4,
                                       Diff Object Signal = 5, etc */
   unsigned short pixelFormat;     /*  0 = short integer  = 2 bytes
                                       1 = long integer   = 4 bytes
                                       2 = float          = 4 bytes
                                       3 = double         = 8 bytes*/
   unsigned short xSize;
   unsigned short ySize;
   unsigned long  trig_count;      /* external trig counter */
   unsigned long  frame_count;     /* frame number in sequence */
   long  spareLong[16];            /* = 0 */
} FPF_IMAGE_DATA_T;
```

5.4.17.3 The camera data structure (360 bytes)

```
/*  String lengths    */
#define FPF_CAMERA_TYPE_LEN   31   /* Camera name string */
#define FPF_CAMERA_PARTN_LEN  31   /* Camera part number string */
#define FPF_CAMERA_SN_LEN     31   /* Scanner serial number string */
#define FPF_LENS_TYPE_LEN     31   /* Lens name string */
#define FPF_LENS_PARTN_LEN    31   /* Lens part number string */
#define FPF_LENS_SN_LEN       31   /* Lens serial number string */
#define FPF_FILTER_TYPE_LEN   31   /* Filter name string */
#define FPF_FILTER_PARTN_LEN  31   /* Filter part number string */
#define FPF_FILTER_SN_LEN     31   /* Filter serial number string */
typedef struct
{
    char camera_name[FPF_CAMERA_TYPE_LEN+1];
    char camera_partn[FPF_CAMERA_PARTN_LEN+1];
    char camera_sn[FPF_CAMERA_SN_LEN+1];

    float camera_range_tmin;
    float camera_range_tmax;

    char lens_name[FPF_LENS_TYPE_LEN+1];
    char lens_partn[FPF_LENS_PARTN_LEN+1];
    char lens_sn[FPF_LENS_SN_LEN+1];
    char filter_name[FPF_FILTER_TYPE_LEN+1];
    char filter_partn[FPF_FILTER_PARTN_LEN+1];
    char filter_sn[FPF_FILTER_SN_LEN+1];
   long  spareLong[16];             /* = 0 */
}FPF_CAMDATA_T;
```

5.4.17.4 The object parameters data structure (104 bytes)

```
typedef struct
{
   float emissivity;        /* 0 - 1 */
   float objectDistance;    /* Meters */
   float ambTemp;           /* Reflected temperature in Kelvin */
   float atmTemp;           /* Atmospheric temperature in Kelvin */
   float relHum;            /* 0 - 1 */
   float compuTao;          /* Computed atmospheric transmission */
   float estimTao;          /* Estimated atmospheric transmission */
```

```
   float refTemp;           /* Reference temperature in Kelvin */
   float extOptTemp;        /* Kelvin */
   float extOptTrans;       /* 0 - 1 */
   long  spareLong[16];     /* = 0 */
} FPF_OBJECT_PAR_T;
```

5.4.17.5 The date and time data structure (92 bytes)

```
typedef struct
{
   int Year;
   int Month;
   int Day;
   int Hour;
   int Minute;
   int Second;
   int MilliSecond;
   long  spareLong[16];            /* = 0 */
} FPF_DATETIME_T;
```

5.4.17.6 The scaling data structure (88 bytes)

```
typedef struct
{
   float tMinCam;          /* Camera scale min, in current output */
   float tMaxCam;          /* Camera scale max */
   float tMinCalc;         /* Calculated min (almost true min) */
   float tMaxCalc;         /* Calculated max (almost true max) */
   float tMinScale;        /* Scale min */
   float tMaxScale;        /* Scale max */
   long  spareLong[16];    /* = 0 */
} FPF_SCALING_T;
```

5.4.18 Studying parts of images

If one part of the image is particularly interesting, you can put any kind of area around it and save its temperatures in a text file that MS Excel can read. (.csv format)

This command is called **Save area as…**, and is available in the **Image** menu.

5.5 How to measure many images

The previous section was about measurements on single images. Much of what was said there is still valid and will not be repeated here. This section will deal only with questions arising when several images are involved. Typical examples are how a temperature varies with time or how two (or more) measurements vary together.

5.5.1 Making measurements in playback

You can change the scale and the object parameters when playing the images. Then you can choose among the following temperature scales:

- The original scale of the recorded image, the source scale
- A calculated scale, automatically adjusted to the image
- A fixed scale

This is controlled by one button on the **Standard** toolbar and one on the **Play images** toolbar:

10424903;a2

Figure 5.33 **Candle** toolbar button

10425003;a2

Figure 5.34 **Lock scale** toolbar button

If you click on the candle, it will become depressed and a new scale will automatically be calculated for every new image as you play them. If you click again on the candle releasing it or, if you click the **Lock scale** button, the current scale limits will be locked (kept) for every new image. If you release the right button by clicking on it again, the original scale of the images is shown.

If you change the scale manually, and forget to click the lock scale button afterwards, you will be asked **Do you want to use your new scale for all images?**

The following options exist for the object parameters:

- The original parameters of the recorded images
- New, enforced object parameters

This is also controlled from the play recording tools, using this button:

10425103;a2

Figure 5.35 Button used to change object parameters

If it is depressed, the current object parameters are kept for all new images. If it is released, the original object parameters of the images are used.

If you change the object parameters manually, and forget to click the **Lock object parameters** button afterwards, you will be asked **Do you want to use your new object parameters for all images?**

The images recorded by ThermaCAM™ Researcher do not contain any analysis tools. Hence, you have to add them while playing the images. This is very well, as long as the object of interest stands still. You simply add the analysis and save it with the session file.

Should the object be moving, we recommend going through the images one by one, moving/reshaping the analysis tools for each image, and saving them under the same name. Thus, forcing each image to contain its own set of analysis tools. There is a **Save As** item in the **Image** menu that will do the job.

	In order to make ThermaCAM™ Researcher bother about the analysis of these images in the future, you have to release the **Lock analysis symbols** button for this session.
	It is also possible for you to “lock” the zoom factor, if you like. Each image can contain a different zoom factor. By pressing this button, you keep the same for all images.

If you change the zoom factor manually, and forget to click the lock zoom factor button afterwards, you will be asked **Do you want to use your new zoom factor for all images?**

5.6 How to study temperature profiles

5.6.1 Obtaining a profile

Temperature profiles are useful when you wish to illustrate the temperature variation across or along an object in the image. You just have to put the line on the image and switch to the profile window in order to be able to see the profile. Below the graph, there is a table, in which you can get interesting information about each line.

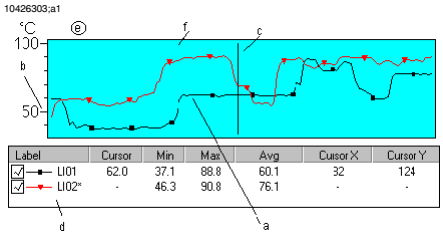

Figure 5.36 A temperature profile (example)

Figure 5.37 Explanations of callouts

a	Profile	d	Profile table
b	Temperature scale	e	Chart area
c	Line cursor	f	Plor area

If you would like to change the way in which the profiles are displayed, you can do this by the **Settings** dialog box, available on the right hand mouse button when you click on top of the profile.

The profile scale is normally connected to the IR image scale, but can be set independently or automatically.

The line presentation can be reversed, in case you happened to draw the line in the wrong direction.

Each line can have a cursor, which is displayed both in the profile window and the IR image. When you need to find the image position of a certain "bump" in the profile, add a cursor tool to the line and move it in the IR image until it hits the bump.

5.6.2 Transferring temperature profile data using OLE

The profile of each line or area is available in table form if you select **String data** for a line from the **Copy Value** dialog box of the **Edit** menu. In the receiving application, for example MS Excel, select **Edit** → **Paste Special**.

You can also right click inside the profile window and select **Copy**. When pasting, choose either **Text** or **Picture (Enhanced Metafile)**. The **Text** option copies the profile table contents and the **Picture** option copies the entire profile in graphical format.

5

5.7 How to study temperature distributions

5.7.1 Obtaining a histogram

The easiest way to assess the distribution of temperatures within an area or along a line on the image is to look at the histogram, which displays how much of the area/line that is occupied by a certain temperature interval. You simply put the area/line on the image and switch over to the histogram window. Below the bar graph, there is a table, in which you select which analysis tool to display.

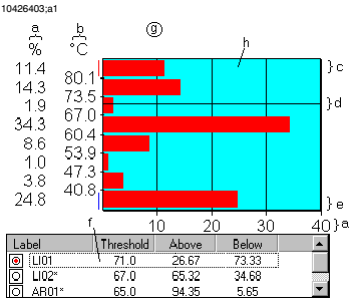

Figure 5.38 A histogram (example)

Figure 5.39 Explanations of callouts

a	The percentage value for each class	e	Underflow class, marked by a blue line by the scale
b	Class temperature limits	f	Histogram table, indicating the active histogram
c	Overflow class, marked by a red line by the scale	g	Chart area
d	Threshold indicator	h	Plot area

If you would like to change the number of class intervals or the top/bottom limit of the histogram scale, this can be done by the **Settings** dialog box, available on the right hand mouse button when you click on top of the histogram. The permitted number of classes is 2–64.

The histogram scale is normally connected to the IR image scale, but can be set differently. Changing this does not, however, change the class interval limits that always are determined by the current IR image scale.

Those parts of the area/line that fall outside the IR scale are included in the overflow/underflow classes.

If you want to be able to see and compare two histograms at the same time you must switch the histogram window over to dual histogram mode. Afterwards, you can select two analysis tools for display at the same time.

5.7.2 Using a threshold

Let's suppose that you are not interested in the full temperature distribution of a line/area, just in getting to know how much of it that has been sufficiently heated or cooled. Then the threshold function will suit your purpose.

You can associate a threshold with a line/area from the **Analysis** tab of the IR image settings or the **General** tab of the **Histogram** window Settings and obtain the desired percentage from the **Result Table** window or the **Histogram** window, if you switch on its presentation. The threshold can also be displayed in the histogram bar graph.

Temperatures that are equal to the threshold temperature are counted as below the threshold.

The threshold does not have to coincide with any class limit of the histogram window.

5.7.3 Transferring temperature distribution data using OLE

The histogram of each line or area is available in table form if you select **Histogram** from the **Copy Value** dialog box of the **Edit** menu. In the receiving application, for example MS Excel, select **Edit** → **Paste Special**.

You can also right -click inside the histogram window and select **Copy**. When pasting, choose either **Text** or **Picture (Enhanced Metafile)**. The **Text** option copies the histogram table contents and the **Picture** option copies the entire histogram in graphical format.

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6 Menu commands

6.1 File menu

This menu contains commands related to session files. You can create new sessions, open existing session files, save the current session, select a default session, open/add images to the current session, print an image and leave the program. You can also save the current tab as a bitmap file.

SEE ALSO: For more information, see sections:

- 4.4 – Session files on page 8
- 5.1.1 – Open images dialog box on page 15

6.2 Edit menu

This menu contains commands related to the clipboard.

SEE ALSO: For more information, see sections:

- 5.3.2 – Transferring an IR image with OLE on page 25
- 5.1 – How to play back images on page 15
- 5.4.12 – Transferring single results with OLE on page 35

6.3 View menu

This menu lists all the toolbars, the control panels and the status line of ThermaCAM™ Researcher. Use this menu to hide and unhide them as you please.

SEE ALSO: For more information about tools and toolbar buttons, see section:

- 4.5 – Program screen layout on page 9

6.4 Image menu

This menu leads to most commands related to the handling of single images.

SEE ALSO: For more information, see sections:

- 4.3 – Image directory on page 7
- 5.1.1 – Open images dialog box on page 15
- 5.3.1 – Obtaining a good IR image on page 22
- 5.4.14 – Measurement output and units on page 36
- 5.4.15 – Studying whole images on page 37
- 5.4.7 – Removal of analysis tools on page 32
- 5.4.18 – Studying parts of images on page 41
- 5.4.9 – Emissivity calculation on page 33

6.5 Recording menu

This menu contains commands about the playback of recordings.

SEE ALSO: For more information, see sections:

- 5.1 – How to play back images on page 15
- 5.2 – How to edit/convert sequences on page 20

6.6 Help menu

This menu provides you with access to the ThermaCAM™ Researcher help file, which happens to correspond to this manual, and with version information about ThermaCAM™ Researcher and its components, the IR image control program and the camera control program.

6.7 Play Images toolbar menu

This menu pops up when you click with the right mouse button on the play images tool bar. It contains some of the commands in the **Recording** menu.

SEE ALSO: For more information, see sections:

- 5.1 – How to play back images on page 15
- 5.2 – How to edit/convert sequences on page 20

6.8 IR Image window menus

These menu pops up when you click with the right mouse button on the IR image.

If you happen to click near an analysis symbol, you will get a menu for that symbol. If you click anywhere else on the IR image, you will get a menu with some of the commands from the IR menu.

SEE ALSO: For more information, see sections:

- 5.1.1 – Open images dialog box on page 15
- 5.3.1 – Obtaining a good IR image on page 22
- 5.4.14 – Measurement output and units on page 36
- 5.4.15 – Studying whole images on page 37
- 5.4.7 – Removal of analysis tools on page 32
- 5.4.18 – Studying parts of images on page 41
- 5.4.9 – Emissivity calculation on page 33

6.9 Results table window menu

This menu pops up when you click with the right mouse button on the **Results** table window. It contains settings for the **Results** table.

SEE ALSO: For more information about the result table, see section:

- 5.4.9 – Emissivity calculation on page 33

6.10 Profile window menu

This menu pops up when you click with the right mouse button on the profile window. It contains settings for the profile window.

SEE ALSO: For more information about the profile, see section:

- 5.6 – How to study temperature profiles on page 43

6.11 Histogram window menu

This menu pops up when you click with the right mouse button on the histogram window. It contains settings for the histogram window.

SEE ALSO: For more information about histogram, see section:

- 5.7 – How to study temperature distributions on page 44

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7 Thermographic measurement techniques

7.1 Introduction

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected temperature
- The distance between the object and the camera
- The relative humidity

7.2 Emissivity

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

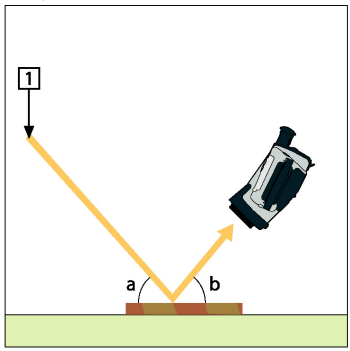
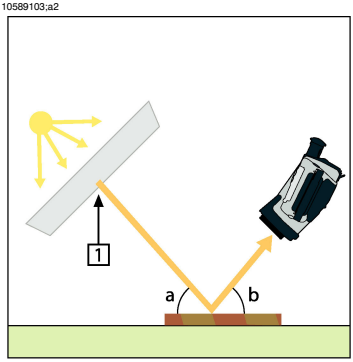
Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

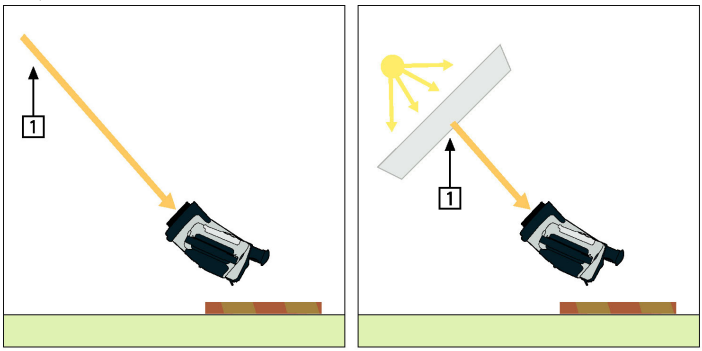
7.2.1 Finding the emissivity of a sample

7.2.1.1 Step 1: Determining reflected apparent temperature

Use one of the following two methods to determine reflected apparent temperature:

7.2.1.1.1 Method 1: Direct method

Step	Action
1	Look for possible reflection sources, considering that the incident angle = reflection angle (a = b). 10588903;a1  **Figure 7.1** 1 = Reflection source
2	If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard. 10589103;a2  **Figure 7.2** 1 = Reflection source

Step	Action
3	Measure the radiation intensity (= apparent temperature) from the reflecting source using the following settings: ▪ Emissivity: 1.0 ▪ D_{obj}: 0 You can measure the radiation intensity using one of the following two methods: 10589003;a2  **Figure 7.3** 1 = Reflection source

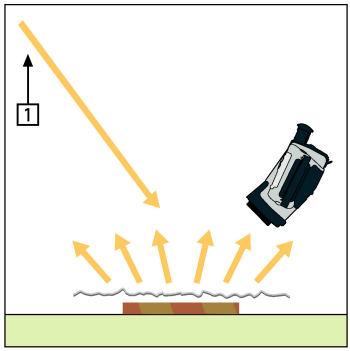
➲ Please note the following:

Using a thermocouple to measure reflecting temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

7.2.1.1.2 Method 2: Reflector method

Step	Action
1	Crumble up a large piece of aluminum foil.
2	Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size.
3	Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera.
4	Set the emissivity to 1.0.

Step	Action
5	Measure the apparent temperature of the aluminum foil and write it down. 10727003;a2  **Figure 7.4** Measuring the apparent temperature of the aluminum foil

7.2.1.2 *Step 2: Determining the emissivity*

Step	Action
1	Select a place to put the sample.
2	Determine and set reflected apparent temperature according to the previous procedure.
3	Put a piece of electrical tape with known high emissivity on the sample.
4	Heat the sample at least 20 K above room temperature. Heating must be reasonably even.
5	Focus and auto-adjust the camera, and freeze the image.
6	Adjust **Level** and **Span** for best image brightness and contrast.
7	Set emissivity to that of the tape (usually 0.97).
8	Measure the temperature of the tape using one of the following measurement functions: ▪ **Isotherm** (helps you to determine both the temperature and how evenly you have heated the sample) ▪ **Spot** (simpler) ▪ **Box Avg** (good for surfaces with varying emissivity).
9	Write down the temperature.
10	Move your measurement function to the sample surface.
11	Change the emissivity setting until you read the same temperature as your previous measurement.

Step	Action
12	Write down the emissivity.

➲ Please note the following:

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

7.3 Distance

The distance is the distance between the object and the front lens of the camera.

This parameter is used to compensate for the fact that radiation is being absorbed between the object and the camera and the fact that transmittance drops with distance.

7.4 Reflected temperature

This parameter is used to compensate for the radiation reflected in the object.

In some cameras, it is also called *background temperature.*

If the emissivity is low and the object temperature relatively close to that of the ambient it will be very important to set and compensate for the reflected temperature correctly.

7.5 Atmospheric temperature, humidity and distance

These parameters are used to correct for the fact that radiation is being absorbed in the atmosphere between the object and the camera and the fact that transmittance drops with distance.

If the humidity of the air is high, the distance very long and the object temperature relatively close to that of the atmosphere it will be important to set and compensate for the atmosphere correctly.

The distance is the distance between the object and the front lens of the camera.

The transmittance is heavily dependent on the relative humidity of the air. To compensate for this, set the relative humidity to the correct value. For short distances of air with normal humidity, the relative humidity can usually be left at a default value of 50 %.

If you have a better estimate of the properties of the atmosphere than the built-in model has, you can enter your estimated transmission value instead.

To avoid applying this type of compensation, please set the estimated transmission to 1.0.

7.6 External optics transmission and temperature

Sometimes, the radiation from the object also has to pass through some optical accessory, such as a heat shield or a macro lens, before reaching the camera. Then that optics, external to the camera, will absorb some of the radiation. To correct for this effect, enter the transmittance and temperature of the optics.

Ambient reflections in the external optics are not taken into consideration mathematically, so the optics either has to have a non-reflective coating or have the same temperature as the ambient (on the camera side) to make the correction work properly.

Please avoid ambient reflections. Do, for instance, make sure that the camera cannot see itself mirrored in the external optics.

To avoid applying this type of compensation, please set the external optics transmission to 1.0.

7.7 Infrared spectral filters

Any object, with a temperature above 0 Kelvin, will emit electromagnetic radiation over a wide spectrum. The hotter the object, the stronger and wider the radiation, and the shorter its wavelength. Infrared detectors are only sensitive in parts of the infrared waveband. This means that the temperature calculations in infrared cameras make assumptions about the amount of radiation present in other wavebands.

Infrared cameras are calibrated with a set of standard blackbodies at various temperatures. Any object in air, behaving like a blackbody, can thus be treated properly by the camera. Sometimes, there are different conditions. Hot gases, for instance, emit radiation only at discrete wavelengths, “stripes”. Cold gases absorb radiation in stripes. To be able to make accurate measurements under such circumstances, you have to use the right spectral filters.

7.8 Units of measure

Thermography really means making images of thermal surface property variations of objects. The most natural property to measure is of course temperature, which has the units Celsius, Fahrenheit and Kelvin in ThermaCAM™ Researcher.

Another interesting property is the total amount of radiation emitted from the object but, since the infrared camera is sensitive only to parts of the spectrum, no accurate such measurement can be made. Hence no standardised unit is available for radiation display. Instead, the non-calibrated unit *object signal* (abbreviated OS) has been in-

vented. Being approximately proportional to the amount of radiation sensed by the camera detector, it can be used for comparative radiation measurements within the same measurement range for the same camera. If you intend to use it in some other way, you have to provide a calibration of your own.

Some measurements, such as the standard deviation, produce a result which best could be described as a *difference temperature* (or *difference object signal*). They involve a subtraction, which cancels out the existing absolute level. A standard deviation of 2.5 at 25 °C is the same thing as a standard deviation of 2.5 at 50 °C. In such cases, the units DeltaCelsius (dC), DeltaFahrenheit (dF), DeltaKelvin (dK) and DeltaObjectSignal (dOS) apply.

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8 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high performance infrared imaging systems and is the world leader in the design, manufacturing and marketing of thermal imaging systems for a wide variety of commercial, industrial and government applications. Today, FLIR Systems includes the history of four major companies with outstanding achievements in infrared technology since 1965—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), and the three U.S. companies Indigo Systems, FSI, and Inframetrics.

10722703;a1

Figure 8.1 LEFT: Thermovision® Model 661 from 1969. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg/13 lb.) can be seen. **RIGHT:** InfraCAM from 2006. Weight: 0.55 kg (1.21 lb.), including battery.

The company has sold more than 40,000 infrared cameras worldwide for applications such as predictive maintenance, R & D, non-destructive testing, process control and automation, machine vision and many others.

FLIR Systems has three manufacturing plants in United States (Portland, OR, Boston, MA, Santa Barbara, CA) and one in Sweden (Stockholm). Direct sales offices in Belgium, Brazil, China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Sweden and USA—together with a world-wide network of agents and distributors—support our international customer base.

FLIR Systems is at the helm of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, the first uncooled infrared camera, to mention but a few innovations.

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing over lenses and system electronics, to final testing and calibration, all production steps are done and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

8.1 More than just an infrared camera

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them the most powerful camera-software combination. Especially tailored software for predictive maintenance, R & D and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

8.2 Sharing our knowledge

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, which provides certified training courses. Attending one of the ITC courses will give you a real hands-on learning experience.

The staff of the ITC is also there to provide you with any application support you may need in putting infrared theory into practice.

8.3 Supporting our customers

FLIR Systems operates a worldwide service network to keep your camera running at all times. If there should be a problem with your camera, local service centers have all the equipment and know-how to solve it within the shortest possible time. Hence, there is no need to send your camera to the other end of the world or to talk to someone who is not speaking your language.

8.4 A few images from our facilities

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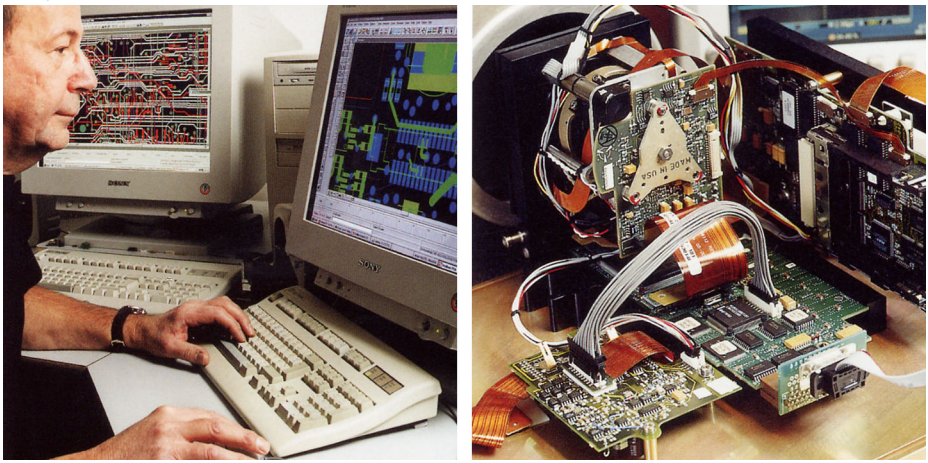

Figure 8.2 LEFT: Development of system electronics; **RIGHT:** Testing of an FPA detector.

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Figure 8.3 LEFT: Diamond turning machine; **RIGHT:** Lens polishing.

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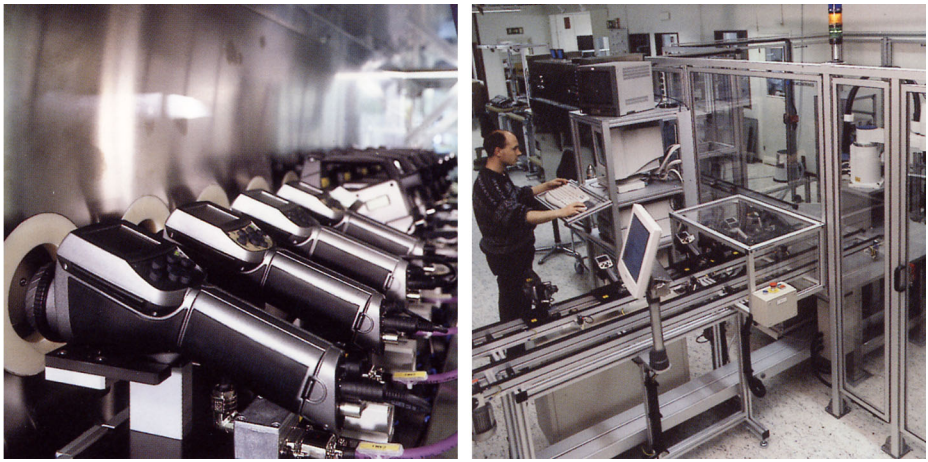

Figure 8.4 LEFT: Testing of IR cameras in the climatic chamber; **RIGHT:** Robot for camera testing and calibration.

9 History of infrared technology

Less than 200 years ago the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply 'the infrared' as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

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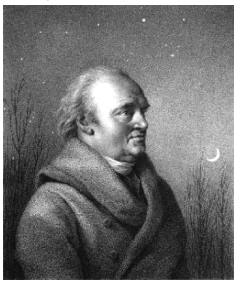

Figure 9.1 Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel—Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus—was searching for an optical filter material to reduce the brightness of the sun's image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun's heat, while others passed so much heat that he risked eye damage after only a few seconds' observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton's prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun's rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel,

however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

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Figure 9.2 Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end—in what is known today as the 'infrared wavelengths.'

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the 'thermometrical spectrum.' The radiation itself he sometimes referred to as 'dark heat,' or simply 'the invisible rays,' Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term 'infrared.' The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel's use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl)—which was available in large enough natural crystals to be made into lenses and prisms—is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930's.

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Figure 9.3 Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel's own thermometer could be read to 0.2°C (0.036°F), and later models were able to be read to 0.05°C (0.09°F). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation—capable of detecting the heat from a person standing 3 meters away (10 ft.).

The first so-called 'heat-picture' became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a 'thermograph.'

10399003;a2

Figure 9.4 Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters (1311 ft.).

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of −196°C (−320.8°F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common 'thermos bottle', used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world 'discovered' the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships—and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and 'flying torpedo' guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally 'see in the dark.' However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer's position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active' (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing 'passive' (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950's, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

10 Theory of thermography

10.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

10.2 The electromagnetic spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

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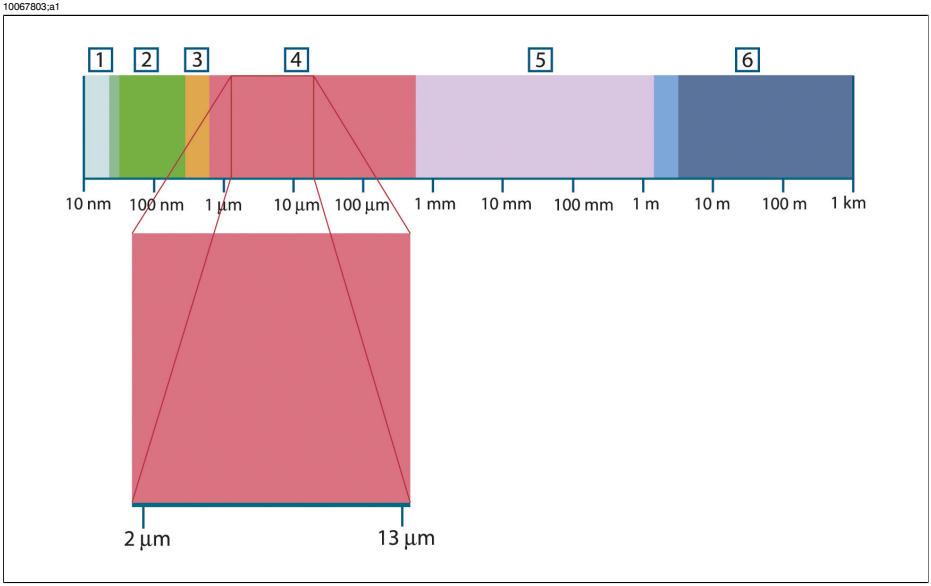

Figure 10.1 The electromagnetic spectrum. **1:** X-ray; **2:** UV; **3:** Visible; **4:** IR; **5:** Microwaves; **6:** Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100

µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

10.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

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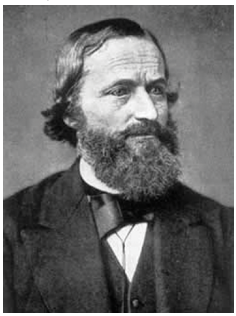

Figure 10.2 Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525 °C (977 °F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

10.3.1 Planck's law

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Figure 10.3 Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5\left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6}[Watt/m^2, \mu m]$$

where:

$W_{\lambda b}$	Blackbody spectral radiant emittance at wavelength λ.
c	Velocity of light = 3×10^8 m/s
h	Planck's constant = 6.6×10^{-34} Joule sec.
k	Boltzmann's constant = 1.4×10^{-23} Joule/K.
T	Absolute temperature (K) of a blackbody.
λ	Wavelength (µm).

➲ The factor 10^{-6} is used since spectral emittance in the curves is expressed in Watt/m^2, µm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at $\lambda = 0$, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

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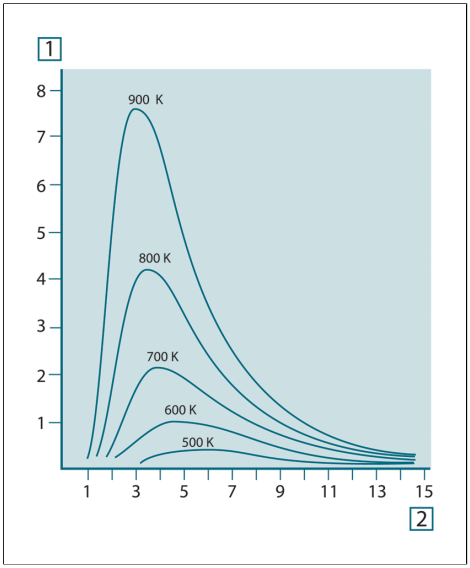

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Figure 10.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. **1:** Spectral radiant emittance (W/cm^2 × 10^3(µm)); **2:** Wavelength (µm)

10.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{max}. A good approximation of the value of λ_{max} for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T

µm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 µm.

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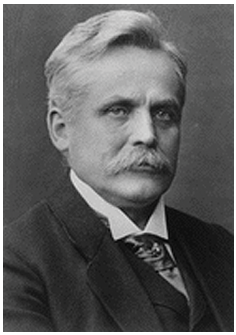

Figure 10.5 Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

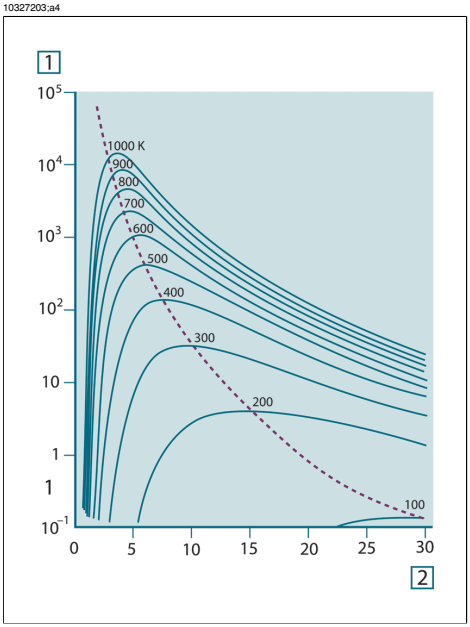

Figure 10.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. **1:** Spectral radiant emittance (W/cm^2 (µm)); **2:** Wavelength (µm).

10.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$, we obtain the total radiant emittance (W_b) of a blackbody:

10

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval $\lambda = 0$ to λ_{max} is only 25 % of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

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Figure 10.7 Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m^2, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

10.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ = the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\alpha_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity ε_λ= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1
- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \, [\mathrm{Watt/m^2}]$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

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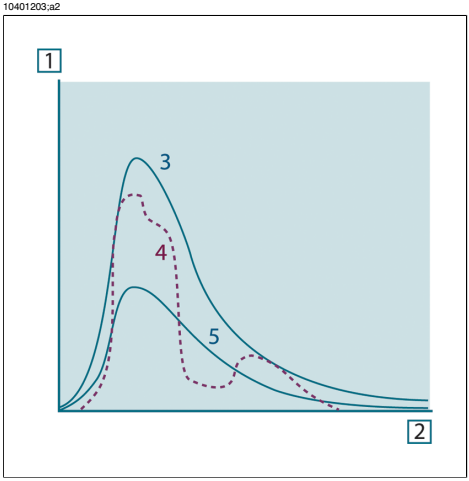

Figure 10.8 Spectral radiant emittance of three types of radiators. **1:** Spectral radiant emittance; **2:** Wavelength; **3:** Blackbody; **4:** Selective radiator; **5:** Graybody.

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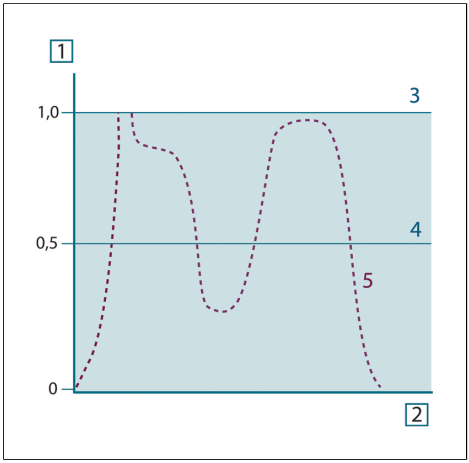

Figure 10.9 Spectral emissivity of three types of radiators. **1:** Spectral emissivity; **2:** Wavelength; **3:** Blackbody; **4:** Graybody; **5:** Selective radiator.

10.4 Infrared semi-transparent materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but

some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

11 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

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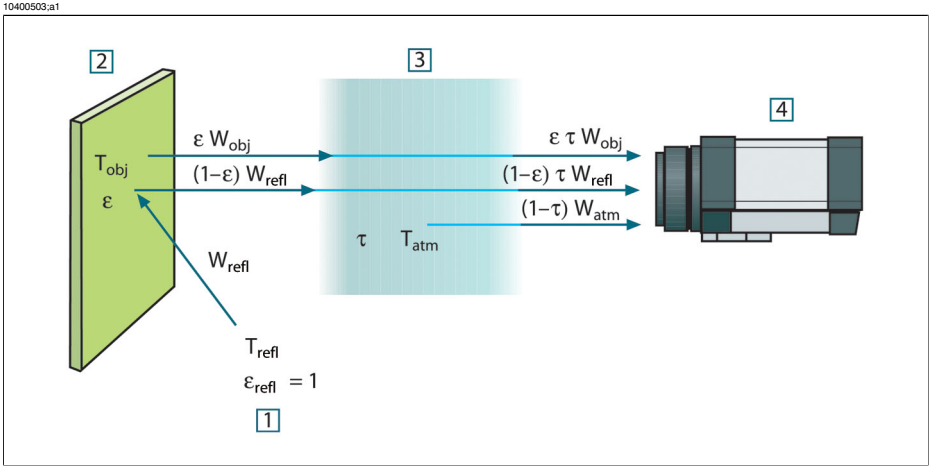

Figure 11.1 A schematic representation of the general thermographic measurement situation.**1:** Surroundings; **2:** Object; **3:** Atmosphere; **4:** Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be εW_{source}.

We are now ready to write the three collected radiation power terms:

1 – Emission from the object = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.

2 – Reflected emission from ambient sources = $(1 - \varepsilon)\tau W_{refl}$, where (1 – ε) is the reflectance of the object. The ambient sources have the temperature T_{refl}.

It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)

3 – Emission from the atmosphere = $(1 - \tau)\tau W_{atm}$, where (1 – τ) is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1 - \varepsilon)\tau W_{refl} + (1 - \tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1 - \varepsilon)\tau U_{refl} + (1 - \tau)U_{atm}$$

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

Figure 11.2 Voltages

U_{obj}	Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
U_{tot}	Measured camera output voltage for the actual case.
U_{refl}	Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
U_{atm}	Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- T_{atm}
- object distance (D_{obj})
- the (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl}, and
- the temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- T_{refl} = +20 °C (+68 °F)
- T_{atm} = +20 °C (+68 °F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the 'disturbing' radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure U_{tot} = 4.5 volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in U_{obj} = 4.5 / 0.75 / 0.92 – 0.5 = 6.0. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

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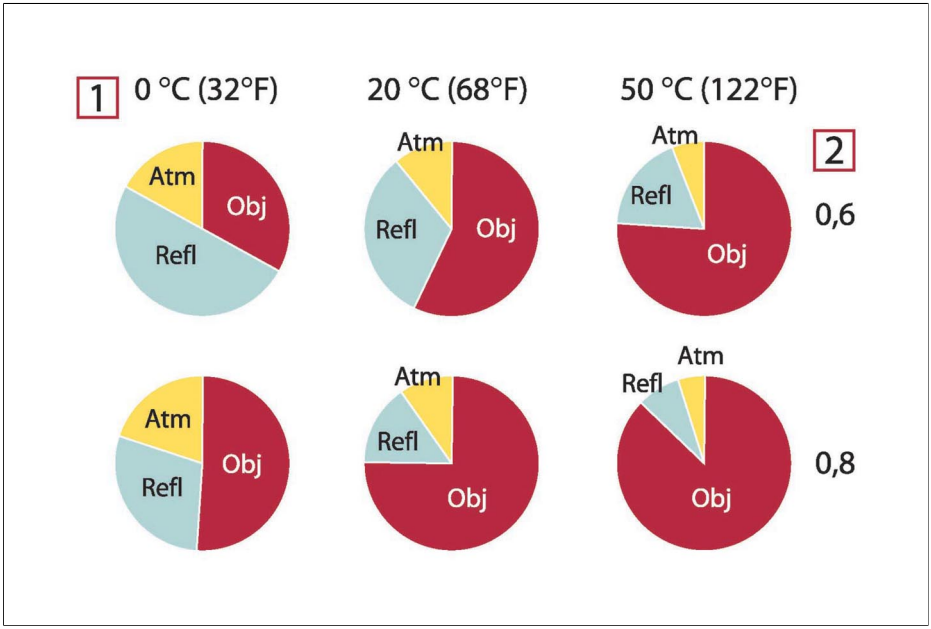

Figure 11.3 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20$ °C (+68 °F); $T_{atm} = 20$ °C (+68 °F).

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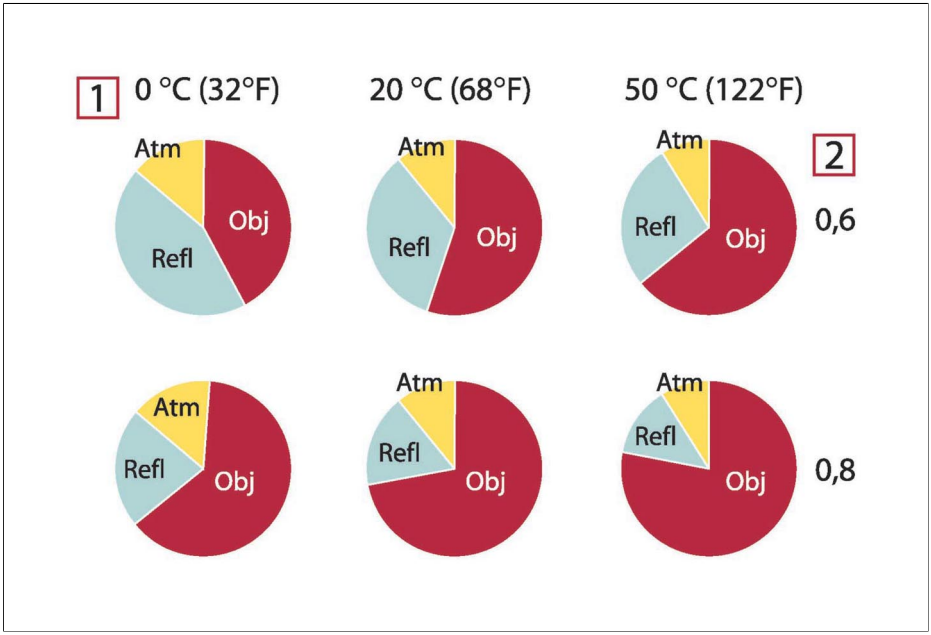

Figure 11.4 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). **1:** Object temperature; **2:** Emittance; **Obj:** Object radiation; **Refl:** Reflected radiation; **Atm:** atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20$ °C (+68 °F); $T_{atm} = 20$ °C (+68 °F).

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12 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

12.1 References

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7	Vlcek, J: *Determination of emissivity with imaging radiometers and some emissivities at* $\lambda = 5$ *µm.* Photogrammetric Engineering and Remote Sensing.
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12.2 Important note about the emissivity tables

The emissivity values in the table below are recorded using a shortwave (SW) camera. The values should be regarded as recommendations only and used by caution.

12.3 Tables

Figure 12.1 T: Total spectrum; **SW:** 2–5 µm; **LW:** 8–14 µm, **LLW:** 6.5–20 µm; **1:** Material; **2:** Specification; **3:** Temperature in °C; **4:** Spectrum; **5:** Emissivity: **6:** Reference

1	2	3	4	5	6
Aluminum	anodized, black, dull	70	LW	0.95	9
Aluminum	anodized, black, dull	70	SW	0.67	9

1	2	3	4	5	6
Aluminum	anodized, light gray, dull	70	LW	0.97	9
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	dipped in HNO_3, plate	100	T	0.05	4
Aluminum	foil	27	3 μm	0.09	3
Aluminum	foil	27	10 μm	0.04	3
Aluminum	oxidized, strongly	50–500	T	0.2–0.3	1
Aluminum	polished	50–100	T	0.04–0.06	1
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	polished plate	100	T	0.05	4
Aluminum	roughened	27	3 μm	0.28	3
Aluminum	roughened	27	10 μm	0.18	3
Aluminum	rough surface	20–50	T	0.06–0.07	1
Aluminum	sheet, 4 samples differently scratched	70	LW	0.03–0.06	9
Aluminum	sheet, 4 samples differently scratched	70	SW	0.05–0.08	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83–0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1

1	2	3	4	5	6
Aluminum oxide	pure, powder (alumina)		T	0.16	1
Asbestos	board	20	T	0.96	1
Asbestos	fabric		T	0.78	1
Asbestos	floor tile	35	SW	0.94	7
Asbestos	paper	40–400	T	0.93–0.95	1
Asbestos	powder		T	0.40–0.60	1
Asbestos	slate	20	T	0.96	1
Asphalt paving		4	LLW	0.967	8
Brass	dull, tarnished	20–350	T	0.22	1
Brass	oxidized	70	SW	0.04–0.09	9
Brass	oxidized	70	LW	0.03–0.07	9
Brass	oxidized	100	T	0.61	2
Brass	oxidized at 600 °C	200–600	T	0.59–0.61	1
Brass	polished	200	T	0.03	1
Brass	polished, highly	100	T	0.03	2
Brass	rubbed with 80-grit emery	20	T	0.20	2
Brass	sheet, rolled	20	T	0.06	1
Brass	sheet, worked with emery	20	T	0.2	1
Brick	alumina	17	SW	0.68	5
Brick	common	17	SW	0.86–0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	fireclay	20	T	0.85	1

1	2	3	4	5	6
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88–0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000–1300	T	0.38	1
Brick	refractory, strongly radiating	500–1000	T	0.8–0.9	1
Brick	refractory, weakly radiating	500–1000	T	0.65–0.75	1
Brick	silica, 95 % SiO_2	1230	T	0.66	1
Brick	sillimanite, 33 % SiO_2, 64 % Al_2O_3	1500	T	0.29	1
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50–150	T	0.55	1
Bronze	powder		T	0.76–0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1
Carbon	graphite, filed surface	20	T	0.98	2
Carbon	graphite powder		T	0.97	1
Carbon	lampblack	20–400	T	0.95–0.97	1
Chipboard	untreated	20	SW	0.90	6

1	2	3	4	5	6
Chromium	polished	50	T	0.10	1
Chromium	polished	500–1000	T	0.28–0.38	1
Clay	fired	70	T	0.91	1
Cloth	black	20	T	0.98	1
Concrete		20	T	0.92	2
Concrete	dry	36	SW	0.95	7
Concrete	rough	17	SW	0.97	5
Concrete	walkway	5	LLW	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	–34	T	0.006	4
Copper	molten	1100–1300	T	0.13–0.15	1
Copper	oxidized	50	T	0.6–0.7	1
Copper	oxidized, black	27	T	0.78	4
Copper	oxidized, heavily	20	T	0.78	2
Copper	oxidized to blackness		T	0.88	1
Copper	polished	50–100	T	0.02	1
Copper	polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	scraped	27	T	0.07	4
Copper dioxide	powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1

1	2	3	4	5	6
Ebonite			T	0.89	1
Emery	coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	lacquer	20	T	0.85–0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	masonite	70	LW	0.88	9
Fiber board	masonite	70	SW	0.75	9
Fiber board	particle board	70	LW	0.89	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	porous, untreated	20	SW	0.85	6
Gold	polished	130	T	0.018	1
Gold	polished, carefully	200–600	T	0.02–0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	polished	20	LLW	0.849	8
Granite	rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	LW	0.77–0.87	9
Granite	rough, 4 different samples	70	SW	0.95–0.97	9
Gypsum		20	T	0.8–0.9	1
Ice: See Water					
Iron, cast	casting	50	T	0.81	1
Iron, cast	ingots	1000	T	0.95	1
Iron, cast	liquid	1300	T	0.28	1
Iron, cast	machined	800–1000	T	0.60–0.70	1
Iron, cast	oxidized	38	T	0.63	4
Iron, cast	oxidized	100	T	0.64	2
Iron, cast	oxidized	260	T	0.66	4
Iron, cast	oxidized	538	T	0.76	4

1	2	3	4	5	6
Iron, cast	oxidized at 600 °C	200–600	T	0.64–0.78	1
Iron, cast	polished	38	T	0.21	4
Iron, cast	polished	40	T	0.21	2
Iron, cast	polished	200	T	0.21	1
Iron, cast	unworked	900–1100	T	0.87–0.95	1
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	covered with red rust	20	T	0.61–0.85	1
Iron and steel	electrolytic	22	T	0.05	4
Iron and steel	electrolytic	100	T	0.05	4
Iron and steel	electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175–225	T	0.05–0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950–1100	T	0.55–0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2
Iron and steel	hot rolled	20	T	0.77	1
Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	oxidized	100	T	0.74	1
Iron and steel	oxidized	100	T	0.74	4
Iron and steel	oxidized	125–525	T	0.78–0.82	1
Iron and steel	oxidized	200	T	0.79	2
Iron and steel	oxidized	1227	T	0.89	4
Iron and steel	oxidized	200–600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	polished	100	T	0.07	2

1	2	3	4	5	6
Iron and steel	polished	400–1000	T	0.14–0.38	1
Iron and steel	polished sheet	750–1050	T	0.52–0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rough, plane surface	50	T	0.95–0.98	1
Iron and steel	rusted, heavily	17	SW	0.96	5
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	shiny oxide layer, sheet,	20	T	0.82	1
Iron and steel	wrought, carefully polished	40–250	T	0.28	1
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1
Iron tinned	sheet	24	T	0.064	4
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92–0.94	9
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50–0.53	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	bakelite	80	T	0.83	1
Lacquer	black, dull	40–100	T	0.96–0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1

1	2	3	4	5	6
Lacquer	heat–resistant	100	T	0.92	1
Lacquer	white	40–100	T	0.8–0.95	1
Lacquer	white	100	T	0.92	2
Lead	oxidized, gray	20	T	0.28	1
Lead	oxidized, gray	22	T	0.28	4
Lead	oxidized at 200 °C	200	T	0.63	1
Lead	shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1
Leather	tanned		T	0.75–0.80	1
Lime			T	0.3–0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4
Magnesium		538	T	0.18	4
Magnesium	polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		600–1000	T	0.08–0.13	1
Molybdenum		1500–2200	T	0.19–0.26	1
Molybdenum	filament	700–2500	T	0.1–0.3	1
Mortar		17	SW	0.87	5
Mortar	dry	36	SW	0.94	7
Nichrome	rolled	700	T	0.25	1
Nichrome	sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500–1000	T	0.71–0.79	1
Nichrome	wire, oxidized	50–500	T	0.95–0.98	1

1	2	3	4	5	6
Nickel	bright matte	122	T	0.041	4
Nickel	commercially pure, polished	100	T	0.045	1
Nickel	commercially pure, polished	200–400	T	0.07–0.09	1
Nickel	electrolytic	22	T	0.04	4
Nickel	electrolytic	38	T	0.06	4
Nickel	electrolytic	260	T	0.07	4
Nickel	electrolytic	538	T	0.10	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	electroplated on iron, polished	22	T	0.045	4
Nickel	electroplated on iron, unpolished	20	T	0.11–0.40	1
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	oxidized	200	T	0.37	2
Nickel	oxidized	227	T	0.37	4
Nickel	oxidized	1227	T	0.85	4
Nickel	oxidized at 600 °C	200–600	T	0.37–0.48	1
Nickel	polished	122	T	0.045	4
Nickel	wire	200–1000	T	0.1–0.2	1
Nickel oxide		500–650	T	0.52–0.59	1
Nickel oxide		1000–1250	T	0.75–0.86	1
Oil, lubricating	0.025 mm film	20	T	0.27	2
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2

1	2	3	4	5	6
Paint	8 different colors and qualities	70	LW	0.92–0.94	9
Paint	8 different colors and qualities	70	SW	0.88–0.96	9
Paint	Aluminum, various ages	50–100	T	0.27–0.67	1
Paint	cadmium yellow		T	0.28–0.33	1
Paint	chrome green		T	0.65–0.70	1
Paint	cobalt blue		T	0.7–0.8	1
Paint	oil	17	SW	0.87	5
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92–0.96	1
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	LW	0.92–0.94	9
Paper	4 different colors	70	SW	0.68–0.74	9
Paper	black		T	0.90	1
Paper	black, dull		T	0.94	1
Paper	black, dull	70	LW	0.89	9
Paper	black, dull	70	SW	0.86	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	green		T	0.85	1
Paper	red		T	0.76	1
Paper	white	20	T	0.7–0.9	1

1	2	3	4	5	6
Paper	white, 3 different glosses	70	LW	0.88–0.90	9
Paper	white, 3 different glosses	70	SW	0.76–0.78	9
Paper	white bond	20	T	0.93	2
Paper	yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9
Plastic	polyurethane isolation board	70	LW	0.55	9
Plastic	polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Plastic	PVC, plastic floor, dull, structured	70	SW	0.94	9
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		100	T	0.05	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum		1000–1500	T	0.14–0.18	1
Platinum		1094	T	0.18	4
Platinum	pure, polished	200–600	T	0.05–0.10	1
Platinum	ribbon	900–1100	T	0.12–0.17	1

1	2	3	4	5	6
Platinum	wire	50–200	T	0.06–0.07	1
Platinum	wire	500–1000	T	0.10–0.16	1
Platinum	wire	1400	T	0.18	1
Porcelain	glazed	20	T	0.92	1
Porcelain	white, shiny		T	0.70–0.75	1
Rubber	hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	polished	19	LLW	0.909	8
Sandstone	rough	19	LLW	0.935	8
Silver	polished	100	T	0.03	2
Silver	pure, polished	200–600	T	0.02–0.03	1
Skin	human	32	T	0.98	2
Slag	boiler	0–100	T	0.97–0.93	1
Slag	boiler	200–500	T	0.89–0.78	1
Slag	boiler	600–1200	T	0.76–0.70	1
Slag	boiler	1400–1800	T	0.69–0.67	1
Snow: See Water					
Soil	dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2
Stainless steel	alloy, 8 % Ni, 18 % Cr	500	T	0.35	1
Stainless steel	rolled	700	T	0.45	1
Stainless steel	sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, polished	70	SW	0.18	9

1	2	3	4	5	6
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxidized at 800 °C	60	T	0.85	2
Stucco	rough, lime	10–90	T	0.91	1
Styrofoam	insulation	37	SW	0.60	7
Tar			T	0.79–0.84	1
Tar	paper	20	T	0.91–0.93	1
Tile	glazed	17	SW	0.94	5
Tin	burnished	20–50	T	0.04–0.06	1
Tin	tin–plated sheet iron	100	T	0.07	2
Titanium	oxidized at 540 °C	200	T	0.40	1
Titanium	oxidized at 540 °C	500	T	0.50	1
Titanium	oxidized at 540 °C	1000	T	0.60	1
Titanium	polished	200	T	0.15	1
Titanium	polished	500	T	0.20	1
Titanium	polished	1000	T	0.36	1
Tungsten		200	T	0.05	1
Tungsten		600–1000	T	0.1–0.16	1
Tungsten		1500–2200	T	0.24–0.31	1
Tungsten	filament	3300	T	0.39	1
Varnish	flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	LW	0.90–0.93	9
Varnish	on oak parquet floor	70	SW	0.90	9

1	2	3	4	5	6
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	distilled	20	T	0.96	2
Water	frost crystals	–10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	–10	T	0.96	2
Water	ice, smooth	0	T	0.97	1
Water	layer >0.1 mm thick	0–100	T	0.95–0.98	1
Water	snow		T	0.8	1
Water	snow	–10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	ground		T	0.5–0.7	1
Wood	pine, 4 different samples	70	LW	0.81–0.89	9
Wood	pine, 4 different samples	70	SW	0.67–0.75	9
Wood	planed	20	T	0.8–0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	LW	0.88	9
Wood	planed oak	70	SW	0.77	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreated	20	SW	0.83	6
Wood	white, damp	20	T	0.7–0.8	1
Zinc	oxidized at 400 °C	400	T	0.11	1
Zinc	oxidized surface	1000–1200	T	0.50–0.60	1

1	2	3	4	5	6
Zinc	polished	200–300	T	0.04–0.05	1
Zinc	sheet	50	T	0.20	1

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A note on the technical production of this manual

This manual was produced using XML – eXtensible Markup Language. For more information about XML, visit the following site:

- http://www.w3.org/XML/

Readers interested in the history & theory of markup languages may also want to visit the following sites:

- http://www.gla.ac.uk/staff/strategy/information/socarcpj/
- http://www.renater.fr/Video/2002ATHENS/P/DC/History/plan.htm

A note on the typeface used in this manual

This manual was typeset using Swiss 721, which is Bitstream's pan-European version of Max Miedinger's Helvetica™ typeface. Max Miedinger was born December 24th, 1910 in Zürich, Switzerland and died March 8th, 1980.

10595503;a1

- 1926–30: Trains as a typesetter in Zürich, after which he attends evening classes at the Kunstgewerbeschule in Zürich.
- 1936–46: Typographer for Globus department store's advertising studio in Zürich.
- 1947–56: Customer counselor and typeface sales representative for the Haas'sche Schriftgießerei in Münchenstein near Basel. From 1956 onwards: freelance graphic artist in Zürich.
- 1956: Eduard Hoffmann, the director of the Haas'sche Schriftgießerei, commissions Miedinger to develop a new sans-serif typeface.
- 1957: The Haas-Grotesk face is introduced.
- 1958: Introduction of the roman (or normal) version of Haas-Grotesk.
- 1959: Introduction of a bold Haas-Grotesk.
- 1960: The typeface changes its name from Neue Haas Grotesk to Helvetica™.
- 1983: Linotype publishes its Neue Helvetica™, based on the earlier Helvetica™.

For more information about Max Miedinger's Helvetica™ typeface, see Lars Muller's book *Helvetica: Homage to a Typeface*, and the following sites:

- http://www.ms-studio.com/articles.html
- http://www.helveticafilm.com/

The following file identities and file versions were used in the formatting stream output for this manual:

20235103.xml a19
20235203.xml a20
20235303.xml a14
20236703.xml a34
20238703.xml b7
20240803.xml a10
20240903.xml a8
20241403.xml a8
20241503.xml a8
20241603.xml a8
20241703.xml a6
20241903.xml a4
20243503.xml a5
20250403.xml a14
20254903.xml a31
20257003.xml a21
20273903.xml a3
R0027.rcp a8
config.xml a5

▪ BELGIUM
FLIR Systems
Uitbreidingstraat 60–62
B-2600 Berchem
BELGIUM
Phone: +32 (0)3 287 87 11
Fax: +32 (0)3 287 87 29
E-mail: info@flir.be
Web: www.flirthermography.com

▪ BRAZIL
FLIR Systems
Av. Antonio Bardella, 320
CEP: 18085-852 Sorocaba
São Paulo
BRAZIL
Phone: +55 15 3238 8070
Fax: +55 15 3238 8071
E-mail: paul.verminnen@flir.com.br
E-mail: flir@flir.com.br
Web: www.flirthermography.com

▪ CANADA
FLIR Systems
5230 South Service Road, Suite #125
Burlington, ON. L7L 5K2
CANADA
Phone: 1 800 613 0507 ext. 30
Fax: 905 639 5488
E-mail: IRCanada@flir.com
Web: www.flirthermography.com

▪ CHINA
FLIR Systems
Beijing Representative Office
Rm 203A, Dongwai Diplomatic Office Building
23 Dongzhimenwai Dajie
Beijing 100600
P.R.C.
Phone: +86 10 8532 2304
Fax: +86 10 8532 2460
E-mail: beijing@flir.com.cn
Web: www.flirthermography.com

▪ CHINA
FLIR Systems
Shanghai Representative Office
Room 6311, West Building
Jin Jiang Hotel
59 Maoming Road (South)
Shanghai 200020
P.R.C.
Phone: +86 21 5466 0286
Fax: +86 21 5466 0289
E-mail: shanghai@flir.com.cn
Web: www.flirthermography.com

▪ CHINA
FLIR Systems
Guangzhou Representative Office
1105 Main Tower, Guang Dong International Hotel
339 Huanshi Dong Road
Guangzhou 510098
P.R.C.
Phone: +86 20 8333 7492
Fax: +86 20 8331 0976
E-mail: guangzhou@flir.com.cn
Web: www.flirthermography.com

▪ FRANCE
FLIR Systems
10 rue Guynemer
92130 Issy les Moulineaux
Cedex
FRANCE
Phone: +33 (0)1 41 33 97 97
Fax: +33 (0)1 47 36 18 32
E-mail: info@flir.fr
Web: www.flirthermography.com

▪ GERMANY
FLIR Systems
Berner Strasse 81
D-60437 Frankfurt am Main
GERMANY
Phone: +49 (0)69 95 00 900
Fax: +49 (0)69 95 00 9040
E-mail: info@flir.de
Web: www.flirthermography.com

▪ GREAT BRITAIN
FLIR Systems
2 Kings Hill Avenue – Kings Hill
West Malling
Kent, ME19 4AQ
UNITED KINGDOM
Phone: +44 (0)1732 220 011
Fax: +44 (0)1732 843 707
E-mail: sales@flir.uk.com
Web: www.flirthermography.com

▪ HONG KONG
FLIR Systems
Room 1613–15, Tower 2
Grand Central Plaza
138 Shatin Rural Committee Rd
Shatin, N.T.
HONG KONG
Phone: +852 27 92 89 55
Fax: +852 27 92 89 52
E-mail: flir@flir.com.hk
Web: www.flirthermography.com

▪ ITALY
FLIR Systems
Via L. Manara, 2
20051 Limbiate (MI)
ITALY
Phone: +39 02 99 45 10 01
Fax: +39 02 99 69 24 08
E-mail: info@flir.it
Web: www.flirthermography.com

▪ JAPAN
FLIR SYSTEMS Japan KK
Nishi-Gotanda Access 8F
3-6-20 Nishi-Gotanda
Shinagawa-Ku
Tokyo 141-0031
JAPAN
Phone: +81 3 6277 5681
Fax: +81 3 6277 5682
E-mail: info@flir.jp
Web: www.flirthermography.com

▪ SWEDEN
FLIR Systems
Worldwide Thermography Center
P.O. Box 3
SE-182 11 Danderyd
SWEDEN
Phone: +46 (0)8 753 25 00
Fax: +46 (0)8 753 23 64
E-mail: sales@flir.se
Web: www.flirthermography.com

▪ USA
FLIR Systems
Corporate headquarters
27700A SW Parkway Avenue
Wilsonville, OR 97070
USA
Phone: +1 503 498 3547
Web: www.flirthermography.com

▪ USA (Primary sales & service contact in USA)
FLIR Systems
USA Thermography Center
16 Esquire Road
North Billerica, MA. 01862
USA
Phone: +1 978 901 8000
Fax: +1 978 901 8887
E-mail: marketing@flir.com
Web: www.flirthermography.com

▪ USA
FLIR Systems
Indigo Operations
70 Castilian Dr.
Goleta, CA 93117-3027
USA
Phone: +1 805 964 9797
Fax: +1 805 685 2711
E-mail: sales@indigosystems.com
Web: www.corebyindigo.com

▪ USA
FLIR Systems
Indigo Operations
IAS Facility
701 John Sims Parkway East
Suite 2B
Niceville, FL 32578
USA
Phone: +1 850 678 4503
Fax: +1 850 678 4992
E-mail: sales@indigosystems.com
Web: www.corebyindigo.com